

**Oak Ridge National Laboratory**  
**review**

Spring 1983

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*"While tested by financial and organizational adversities, the Laboratory . . . remains a vital institution."*

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*"We were recognized . . . for having the best safety record among R&D laboratories."*

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*"The [scientific panel] reviews testify to the impressive technical strengths of ORNL."*

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*"I find new evidence that the Laboratory is an institution of unquestionable vigor, proven accomplishment, and outstanding intellectual strength."*

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*"We have received more IR-100 awards than any other DOE laboratory."*

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**State of the  
Laboratory  
1982**





THE COVER: Laboratory Director Herman Postma, seen here in his office, says that "long-range, high-risk, high-payoff research and development," the theme of ORNL's work and of his 1982 "State of the Laboratory" address, marks a return to tradition for ORNL. His address begins on page 1.

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Oak Ridge National Laboratory

# review

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**OAK RIDGE NATIONAL LABORATORY**  
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# State of the Laboratory-1982

## *Long-Range, High-Risk, High-Payoff Research and Development*

By HERMAN POSTMA

**L**ong-Range, High-Risk, High-Payoff Research and Development has been designated as the theme of the work that we do—or should do—at Oak Ridge National Laboratory. In 1982 the U.S. Department of Energy, the Executive Branch, and Congress closely reexamined the purposes and roles of national laboratories; their studies reaffirmed this particular theme or focus as a central purpose for ORNL and the other national laboratories. Although this theme is reflected in the current organization of the

scientific and technological enterprise in this country, it represents a “return to tradition” for ORNL.

In recent years public attention has focused on our near-term and commercially oriented research and on those science and technology areas that will have a direct or immediate impact on the nation’s economy. Almost always, however, the essential activity of this Laboratory changes far less than do the descriptions or characterizations applied to it by those who sponsor, oversee, request,

and provide our work. Our research and development activities, while always subject to some shifts and changes that reflect the priorities or perceived needs of the moment, nonetheless have strong roots and reflect a continuity of interest and sustained performance that goes beyond annual budget cycles or changes in national administrations.

I will return to this year’s theme with examples of accomplishments that reflect what I think are important characteristics of Long-Range, High-Risk, High-Payoff



R&D. I will also summarize some of the other outstanding technical accomplishments by ORNL staff during 1982 and present my perceptions of some of the important events during the past year, of the long-range outlook for the Laboratory, and of expected new directions in 1983.

This year we are celebrating ORNL's fortieth birthday. According to our historians, ground was broken 40 years ago—February 1, 1943—for the X-10 Graphite Reactor, the original facility at the then Clinton Laboratories, later to become ORNL. On this anniversary it is appropriate to say "Happy Birthday, ORNL" and "Happy Anniversary" to 29 members of our current staff who are members of the "43 Club" in Oak Ridge.

Whether an institution's fortieth birthday is seen to be as symbolically important as that of a person, ORNL's fortieth birthday is a significant milestone. Like last year's celebration of the fortieth anniversary of the first self-sustaining nuclear chain reaction on December 2, 1942, at the University of Chicago, this 40-year milestone is especially important because of the opportunity to recognize those participants who represent for us a direct link with the Laboratory's origins early in 1943. We salute them, and we celebrate the achievements of this past decade—during which time ORNL has strengthened its reputation as one of the world's most respected R&D institutions.

*Chain T. Liu works at the Instron testing facility, which measures the mechanical properties of ductile aluminide alloys at elevated temperatures in controlled environments. The aluminide alloys developed at ORNL exhibit excellent strength and oxidation resistance at high temperatures and, therefore, may be candidates for structural material in high-temperature energy devices.*

## Areas of Uncertainty

Let me begin with some perspectives on the year that has just passed. It was a year dominated by several major events, all with significant potential impacts on the Laboratory. In May Union Carbide announced its decision to withdraw from the operation of ORNL and the other Nuclear Division facilities here and in Paducah. For the second year in a row, we had first the prospect and then the reality of having to reduce employment levels significantly in anticipation of federal budget cuts. Last year several major studies were launched to reexamine the roles

that national laboratories play within DOE and elsewhere in the federal government and to evaluate the quality and effectiveness of their respective contributions. Finally, the year began with the continuing uncertainty about DOE's future as a cabinet-level department in the face of the administration's determination to dismantle it and merge many of its functions into the U.S. Department of Commerce.

With the perspective of hindsight, it is possible now to perceive some positive or stabilizing consequences that have resulted from each of these areas of uncertainty. In short, the omens were not all bad.

4788-82







With respect to the contractor change, the decisions—first to extend the contract for up to three additional years if necessary to smooth the transition and then to replace Union Carbide with a single contractor—have helped to allay many initial fears about the continuity of our operations and about the organizational impacts that might result from large-scale changes. It appears likely that the transition can be accomplished over the next year or two with a minimum of inconvenience or disruption to either programs or personnel. We can expect less of an impact on the essential services and support to our operations at the Y-12 site as a result of the decision to seek a single replacement contractor. Likewise, the continuity of two essential Nuclear Division-wide functions on which we heavily depend in all of our operations—computer sciences and engineering—will probably continue

in much the same way under a new contractor.

The necessary reduction in employment levels to adjust to the FY 1983 budget was another source of concern. Anticipation and planning allowed us to keep to an absolute minimum the disruptive effect on our people and their careers as well as the programs they support. While reductions of the size we faced are never good news, the combination of normal attrition; a large number of voluntary reductions in force; and interplant transfers, many of them to Y-12, kept the actual number of “pink slips” down to about 20 individuals out of the total reduction of 400 positions. Even within that small number, over half had offers of continuing employment that they chose not to accept.

The spate of reviews of the multiprogram laboratories—four of which were proceeding

*Steve Kennel and Linda Foote examine data from an automatic gamma scintillation counter. This instrument allows them to measure the ability of monoclonal antibodies labeled with different isotopes of radioactive iodine to bind specifically to certain tumor cells. The ORNL researchers use their data to single out antibodies that could be potential therapeutic agents because of their ability to deliver drugs or toxic substances to specific targets of the body.*

simultaneously during a portion of this year—received much attention in the technical press and elsewhere as a forewarning of critical assessments and hard times ahead. Quite to the contrary, however, the results, to date, have been positive. On the one hand, the reviews testify to the impressive technical strengths of ORNL and other laboratories, the essential nature of what we do, and the high quality of our contributions. The criticism has focused not on the laboratories themselves but on whether their



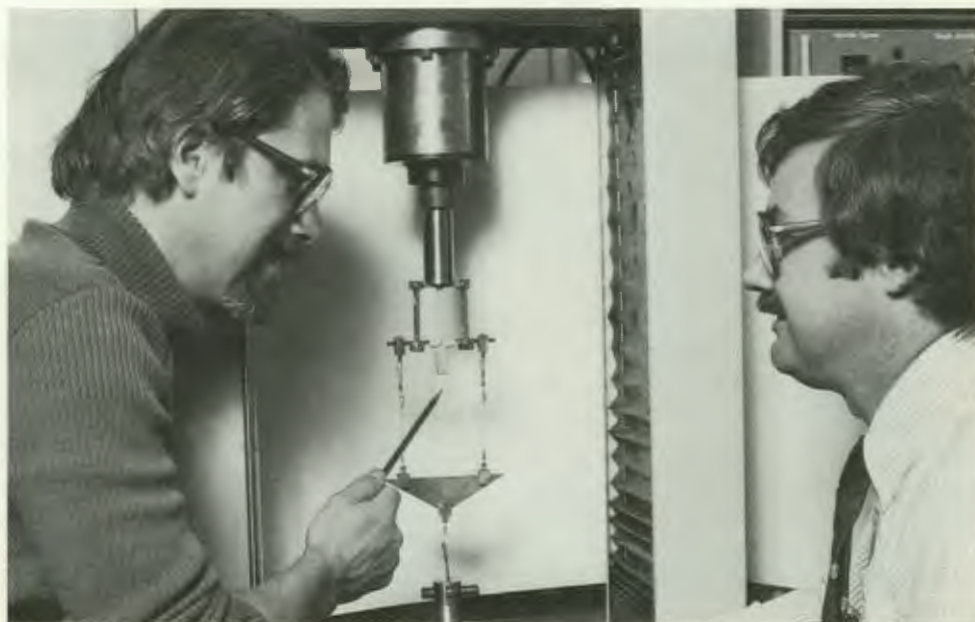
*Paul Becher and Arthur Moorhead examine a toughened ceramic specimen prior to testing it. This particular specimen is used to determine the fracture toughness of the modified ceramic. These researchers have shown that the incorporation of second-phase particles can increase the fracture toughness of ceramics by a factor of 2 to 3.*

impressive capabilities are being fully used in the national interest. Further, the reviews have called attention to some persistent problems related to funding mechanisms, paper-work requirements, and other administrative matters which limit the ability of the national laboratories to fulfill their missions. We hope that one result will be solutions to some of the problems in these areas of continuing concern.

Finally, we have continued this year to share indirectly in many of the side effects of DOE's uncertain future as a cabinet-level department. With the appointment of Donald Hodel as the new DOE secretary, talk of dismantlement has given way to a much clearer sense of direction and a positive approach to the job to be done. Already, in a very short time, the benefits are evident in the improved morale among those with whom we deal in Washington. The question of the long-term organizational niche for energy-related activities in the federal government has by no means been resolved, but stability has returned to the nation's energy programs.

### **Impact of Trends**

Thus, the omens of 1982 that were potentially the most difficult or disquieting for ORNL have turned out to be not all that bad. In fact, sometimes improbably these omens have provided new opportunities and a new sense of direction for ORNL. On the whole, I think that the Laboratory, while tested by many financial and



organizational adversities, has responded with characteristic strength to all of the challenges and remains a vital institution—one that is both needed and appreciated by its sponsors and peers throughout the technical community.

Clearly, however, the sluggish condition of the national economy and the enormous projected federal budget deficits in this and future years will have a continuing impact on ORNL. We also can expect to see our programs affected by narrow, single-issue politics, which has become so dominant a part of our national life today. Both the lack of a publicly evident "energy crisis" and the higher priority given national economic concerns work against the establishment of a clear policy direction and long-term initiatives on energy.

It does seem to me, however, that there is a growing national consensus, in Congress and elsewhere, that high technology and innovation offer the best hope for breaking the cycle of budget deficits, high unemployment, unfavorable trade balances, and other symptoms of economic stagnation. In short, support seems to be building for a much more

concerted effort to encourage high-technology development as the best hope for the nation's economic future. This trend presents enormous challenges and opportunities for our national laboratories. We must continue to set our sights on innovative science and technology as a foundation and stimulus for a broader and more sustained economic growth.

Finally, I find strong support for what I termed earlier a "return to tradition" at ORNL—a Laboratory that continues to be distinguished by a clear sense of its own purpose and direction and a commitment to the highest quality and most imaginative execution of its long-term research and development missions.

### **Defining the Theme**

Particularly in the last year, the Long-Range, High-Risk, High-Payoff R&D criteria have become a quite familiar part of the litany about what national laboratories do—or should do. Much of what the phrase denotes is self-evident. But before turning to some specific examples (out of many) at ORNL of R&D activities that fit these characteristics, I will explain what





Winston Lue, Bob Brown, and John Miller, with their 8T experimental magnet wound with a cable-in-conduit conductor.

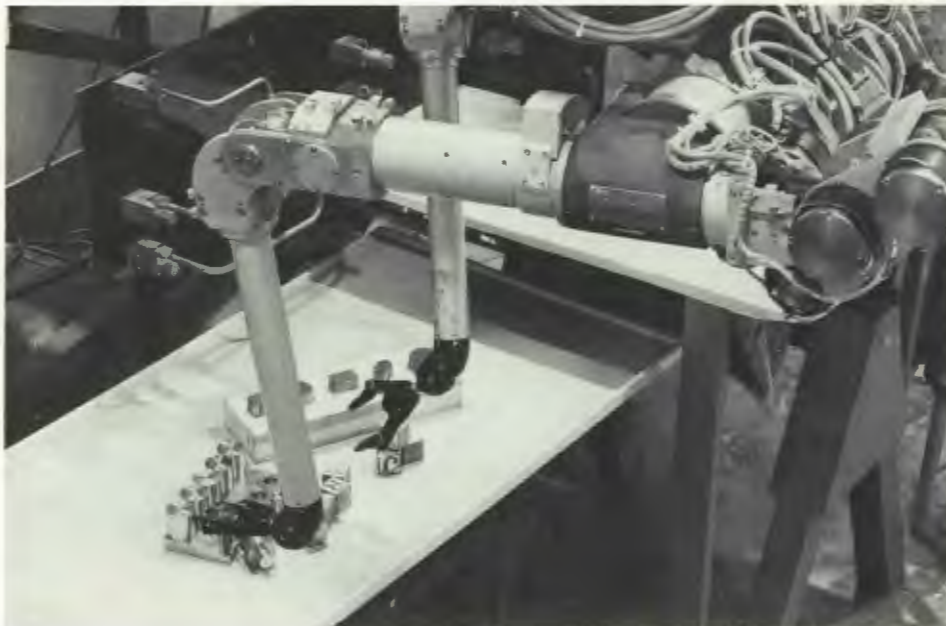
each element of the phrase means to me.

First, "long range" emphasizes the time frame beyond the near-commercial period or, put another way, outside those areas of knowledge and technology which already are receiving substantial attention in industrial or product-development laboratories. The near-commercial period spans only about 5 years rather than the touted 20 years. "Long range" also refers to R&D projects that anticipate and address important needs of our society as we look beyond the immediate future to the twenty-first century. Such R&D requires a sustained commitment over a long period and is seen to offer a high potential for innovation.

## Theme-Related Achievements:

### The Sciences

From the foregoing remarks, it is evident that a large portion of our work, now and in the past, can easily be said to fit the Long-Range, High-Risk, High-Payoff



Remotely controlled manipulators in a cell at the Fuel Recycle Division.

When we speak of "high risk," several key elements come to mind. In the investment sense, it certainly means that the returns are not guaranteed. As a result, industry is less likely to pursue this type of R&D now because the payoff is too distant. Another risk factor may be the high cost on the front end measured against an uncertain return later. Finally, the feasibility or ultimate application of the idea may not be assured.

"High payoff" means that the potential outcome of the R&D work may enormously benefit society in one of several ways: (1) the creation of a virtually unlimited potential resource, (2) a large return on the investment, or (3) the creation of a whole new industry. Any such success might place the United States in a dominant or strongly

competitive position that could improve our balance of payments or simply establish the United States as an international leader in a key field or market sector.

All of these elements, of course, not only define the kind of research deemed most appropriate to a national laboratory but also explain why it is not so likely to take place or be encouraged in academia or industry. To be sure, many areas overlap. Indeed, an important dimension of ORNL's role recently has been the growing interactions with these other sectors through, for example, user-oriented activities of the type described last year in the State of the Laboratory address. Ultimately, we must seek to derive the maximum benefit from the complementary nature of the research interests and needs common to each of these sectors.

R&D theme. To a degree, then, many of the theme-related examples to be cited might be considered interchangeable with the technical highlights that follow, or

vice versa. But those I have selected quite obviously possess the particular characteristics just discussed. From the science areas are two biological examples and



ORNL's automatic noise surveillance and diagnostic system has been demonstrated at TVA's Sequoyah nuclear power plant. Here, Ned Clapp requests information from the system, which has continuously monitored 23 key plant signals at Sequoyah during startup, shutdown, and steady full-power operation.

from the materials sciences a third example.

### Monoclonal Antibodies

New biotechnology has been responsible for significant advances in understanding life processes at the molecular level and in applying this knowledge to problems such as cancer. One example is the ability to make monoclonal antibodies in what now must be regarded as rather routine fashion even if the advances that make it possible remain quite new and remarkable. Monoclonal antibodies are unique in that they (1) bind to a specific type of tumor cell (2) can be isolated in pure form in large quantities, and (3) are reproducible from batch to batch.

Stephen Kennel of the Biology Division has applied this technology to attack experimental solid tumors in mice. For one type of cancer, a viral sarcoma that does not have a human analog, a monoclonal antibody has been isolated that binds to that particular cancer cell but not to normal cells or other kinds of tumors. Kennel found that this antibody alone can destroy relatively large established tumors. From 20 to 30% of the test animals in a given group have been cured, with the cure rate depending on the antibody dose delivered and the size of the tumor at the time of treatment.

Studies of the mechanism of tumor destruction indicate that this antibody has a unique ability to interact with the host's lymphoid cells and that, in concert, they eliminate the tumor cells. Kennel reports that such direct therapy



using monoclonal antibodies already has been successful in the treatment of certain types of human leukemias.

In our own animal studies, we have also prepared monoclonal antibodies that react specifically with several mouse lung carcinomas. For reasons not yet understood, however, these antibodies lack the therapeutic effectiveness of the antibody to the sarcoma tumor. To circumvent this problem, we are attempting to use the specific binding properties of the antibody to deliver toxic agents directly to tumor cells. One benefit of such targeting is that it reduces the relatively severe side effects of cancer chemotherapy.

### Electron Microscope Tomography

The word "tomography" comes from a Greek root that means a cut or a section, as in an electron microscopy photograph of a thin layer of biological material. Through the collaboration of groups in the Biology Division led by Donald and Ada Olins; in the Chemistry Division by Henri Levy; and in the Computer Sciences Division by Richard Durfee, Steve

Margle, and Ed Tinnel, a method has been developed to obtain quantitative three-dimensional (3-D) structural information from sections of biological materials. The technique is of general use because it does not involve a particular orientation or the internal symmetric properties of the materials under study. It is based on an extension of concepts employed in the computerized axial tomography (CAT) scanners now so widely used in medical diagnosis.

Our goal is both to obtain 3-D structural information from sections of biological materials and then to use the reconstructed picture to model the process involved in the actual transcription of hereditary information during ribonucleic acid (RNA) synthesis. The processing sequence has six steps:

- Biological sections are photographed in a modern electron microscope equipped with a stage that tilts the specimen.
- The resulting micrographs are digitized by a scanning camera on line with an image processing system.





*Sweetgum tissue culture.*

*Cottonwood field plot in the state of Washington is one of the sites used by ORNL contractors to screen fast-growing trees for use as fuel.*



- The digitized images are aligned and registered about a common tilt axis.
- By computer algorithms, a 3-D reconstruction of the biological space is developed.
- The reconstruction is displayed in 2- or 3-D sections.
- Models are built and spatial measurements are obtained by analysis of the computer reconstruction.

With this new tool, the Olinses have begun an extensive study of the 3-D structure of RNA synthesis in situ. Currently, they are mapping the spatial arrangement of newly formed ribonucleoproteins around the chromatin axis to search for patterns and calculate parameters, such as the degree of deoxyribonucleic acid (DNA) folding during the transcription process. Future studies will be directed to the regions of DNA replication and the higher levels of folding in chromosomes.

The work now in progress is at the frontier of a number of fields—electron microscopy, chromosome structure, and 3-D computer graphics. The implications extend considerably beyond the problems of immediate study. For example, in the field of cell biology, numerous organelles and supramolecular structures can

be studied by this method, which could help us understand mechanisms of cellular damage induced by chemicals or radiation. In the field of computer graphics, in which ORNL has made pioneering use of digitized information from satellite imagery and ground-based sources for display and analysis of energy-related impacts, the result has been to combine computer hardware and software to quantitatively analyze 3-D images from several sources using electrons and light.

This information may be applied in areas as diverse as robotics and the reconstruction of microscopic objects. Previously, the world of 3-D has been difficult to analyze and visualize in a quantitative manner. The impact of sophisticated imaging processes and display systems in this domain is just beginning to be felt—with vast consequences for a whole range of disciplines from molecular biology to large-scale engineering development.

### **High-Temperature Materials**

Improving the efficiency of energy production and conversion

systems depends mainly on increasing operating temperatures. This, in turn, requires materials that can withstand such higher temperatures. Recognizing this need, several years ago ORNL established the high-temperature materials program as a priority area within the materials sciences. Much of the attack on the problem elsewhere has involved modifying the compositions and methods of processing existing materials. But, with few exceptions, gains have been relatively small.

Our own approach has been to consider new classes of materials that offer the potential for large jumps in performance. Two strong candidates have been ceramics and intermetallic compounds, both recognized for many years for their high-temperature strength. They have not been exploited as structural materials, however, because they are extremely brittle. Nevertheless, our recent work demonstrates that both ceramics and intermetallics can be developed that can be fabricated and that are tough. These promising results based on modern concepts of materials science show that the earlier perceived limitations are not



inherent in the materials and that significant improvements can be made.

Metals are tough because they are able to deform plastically to relieve stresses or to blunt growing cracks. Ceramics, while generally stronger than metals, exhibit only limited plastic deformation. This means that other mechanisms must be found for stopping the growth of flaws or small cracks invariably present in ceramic bodies. Under stress, cracks in ceramics expand slowly until they reach a critical size beyond which they propagate catastrophically, thus causing breakage. This breakage can be prevented if the energy of the running crack can be absorbed in some way, as occurs in metals by plastic deformation.

Ceramists Paul Becher and Arthur Moorhead of the Metals and Ceramics (M&C) Division have pursued two approaches to this problem. In one, particles of tetragonal zirconia ( $ZrO_2$ ) were introduced into a matrix of alumina ( $Al_2O_3$ ). Under stress, a phase transformation occurs, thus resulting in a volume increase of about 4% in the particles. This process absorbs energy and places the region around the particles in compression, thus inhibiting crack growth. Because the desired properties depend on the amount as well as the size, shape, and distribution of the  $ZrO_2$  particles, sol-gel technology developed by the Chemical Technology Division has been used to produce uniform distributions of particles of controlled size.

In the second approach, platinum or chromium particles are dispersed

in the  $Al_2O_3$  matrix. They, too, absorb energy by deforming plastically and can divert or deflect cracks, thereby making crack growth a tortuous process. The resulting material is extremely resistant to thermal shock.

Our tests show that both of these approaches are potent tougheners, thus increasing fracture toughness 200 to 300% above the range for conventional ceramics. Applications of both types of toughened ceramics are expected to include high-efficiency heat engines such as the advanced gas turbine and adiabatic diesel. These developments have come in response to a request from DOE to formulate a long-range plan for a joint industry-laboratory-university program to develop reliable advanced ceramics. The program now has been funded, and ORNL has been named to manage it for DOE.

In another advance in materials science, our recent development of ductile intermetallic compounds paves the way for practical use of lower-cost, aluminum-containing alloys as high-temperature structural materials. These materials are stronger and resist

corrosion better than do stainless steel and the nickel- and cobalt-based "superalloys." They are members of the aluminide family—a series of intermetallic compounds consisting of nickel, aluminum, and other metals that share the characteristics of both metals and ceramics. Although intermetallics based on aluminides are very strong and resistant to corrosion, their use as structural materials is limited because they are normally quite brittle.

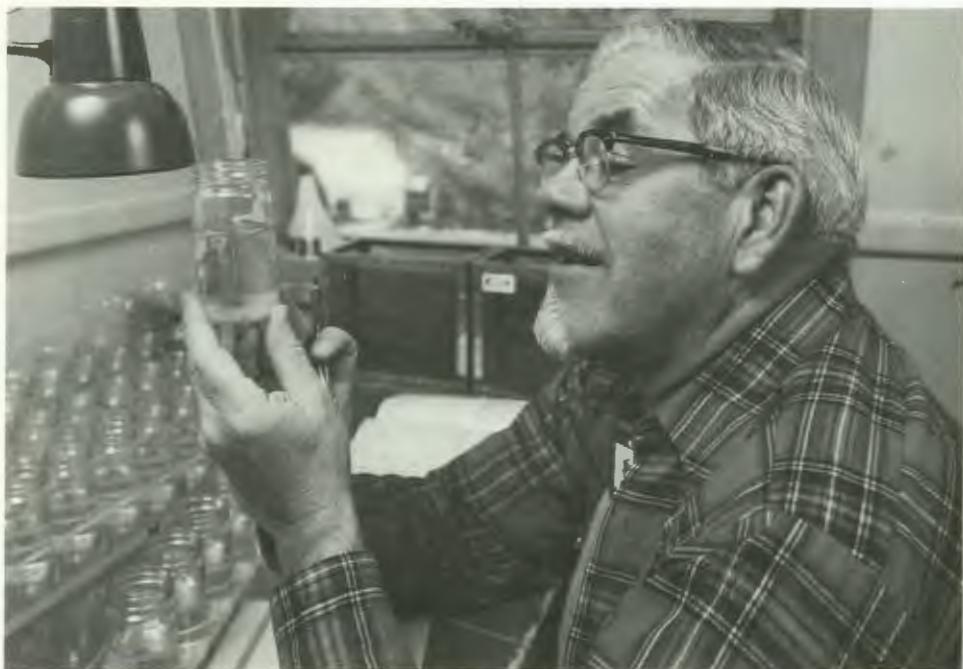
Nickel aluminide ( $Ni_3Al$ ) is an intermetallic long recognized as a high-temperature material. In fact,  $Ni_3Al$  precipitates have been used to strengthen many nickel-based superalloys. However, by itself this material is extremely brittle. Attempts to roll it at  $1200^\circ C$  have generated severe cracks along grain boundaries, for example.

M&C Division metallurgists led by Chain T. Liu, recently found, however, that adding microalloying agents such as boron strengthens the grain boundaries and dramatically improves the overall ductility of nickel aluminides. Specimens containing 500 parts of boron per million exhibit yield

*Bruce Tomkins injects a coal liquid sample into a liquid chromatograph. This instrument allows the preparation of a benzo[a]pyrene-enriched fraction suitable for analysis to determine the effect of hydrotreatment upon the benzo[a]pyrene content of coal liquids.*







*Aubrey Bradshaw examines a culture of water fleas during an experiment to measure the effect of exposure to raw and hydrotreated coal liquids on the survival of these insects (known scientifically as Daphnia magna). ORNL researchers have found that removal of highly toxic phenols by hydrotreatment of water-soluble fractions of coal liquid reduces the liquid's toxicity to the water fleas and other aquatic organisms.*

stresses at 600°C five times as great as those of stainless steel yet retain the steel's excellent characteristics, such as its ability to be fabricated and its ductility. In nickel alloys, according to theory, boron acts as an electron

donor and thus strengthens metal-metal bonds at the grain boundary.

Because of the presence of aluminum, nickel aluminide resists oxidation, thus eliminating the need for chromium, a strategic material. Particularly noteworthy is the

ability of modified aluminide to become stronger at higher temperatures at which other materials grow weaker. Liu has also found that changing the base composition with alloy additions makes the material even stronger.

In short, both the metal-toughened ceramics and ductile intermetallics offer the potential for increasing significantly the operating temperatures of energy production and conversion devices. They represent a quantum step beyond existing materials.

## Theme-Related Achievements:

### The Technologies

We turn now to three theme-related examples from the technology areas—developments involving both fusion and fission energy.

#### **Cable-In-Conduit Superconductors**

To produce energy from fusion economically, the magnets used for confining fusion plasmas in toroidal devices must be energy efficient and reliable. Thus, the large magnets being developed for fusion require superconductors with mechanical strength, unbroken insulation, low alternating current losses, and stability. Of these requirements, the most important is stability against potential thermal and mechanical

disturbances induced by the immense fields and strong forces involved.

In recent years, researchers in the Fusion Energy Division and at the Massachusetts Institute of Technology have shown that internally cooled (or cable-in-conduit) superconductors can meet all of these requirements. Key contributors at ORNL have been Larry Dresner, Winston Lue, John Miller, Robert Brown, and Martin Lubell. The cable-in-conduit design consists of a cabled superconductor and helium coolant in intimate contact inside a thick-walled tube that provides strength. The insulation is unbroken because it completely surrounds the pipe containing the conductor. One

advantage of this wrap-around design is that it protects against accidental electrical arcing from one conductor to another, a phenomenon that can damage a coil. Because the superconductor is finely divided in the form of thin wires, ac losses are low. Also, most importantly, heat transfer from metal to helium is excellent; therefore, stability against thermal perturbation is very high.

Recent work has shown that heat is transferred effectively by powerful momentary flow induced in the helium by the transfer of the heat itself. Because of this heating-augmented heat transfer, cable-in-conduit superconductors can operate stably with much higher current densities than



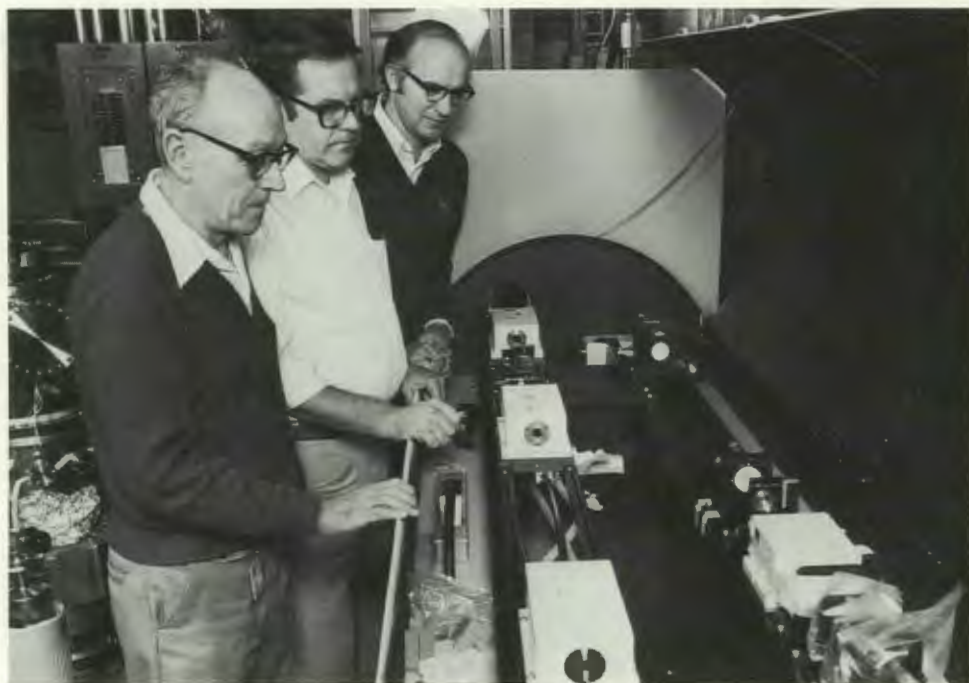
*A ruby pulsed-laser system similar to this one at ORNL was used in the silicon melting studies done at Cornell University. Participants in the research are, from front to back, Tom Noggle, Woody White, and Ben Larson.*

conventional bath-cooled superconductors. Operation at high current density means reduction in magnet size, weight, and cost—all very important practical advantages to system design.

A cable-in-conduit conductor is being used in the coil made by the Westinghouse Electric Corporation for testing next year in ORNL's Large Coil Test Facility (LCTF). Internally cooled coils of a slightly different design are to be used in the Euratom and Swiss coils being assembled for the LCTF tests.

During the last two years, our knowledge of flow transients so improved that we could formulate simple design equations, which have been corroborated by small-scale tests on conductors ranging in capacity from 100 A to more than 20 kA at an operating field of 8 T. These equations recently were used to design a magnet capable of producing an 8-T field on its own, and this magnet has been constructed and successfully operated. Based on stability tests, we are confident that the same design techniques can be applied to much larger coils.

An interesting feature of a magnet wound with cable-in-conduit conductors is that the same level of stability can be maintained at a higher field by reducing the temperature of the helium. This is not the case in a magnet bath-cooled with boiling helium, where stability is limited by heat transfer. This phenomenon means that, as far as stability goes, the output field of a particular magnet is tied directly to the available refrigeration power. The researchers also showed that this method of cooling is not limited to



niobium-tin as a superconductor material; niobium-titanium also can be used in a cable-in-conduit design to high fields. This development is an impressive contribution to one of the key technologies that will be required to make magnetic fusion energy economical and reliable.

### Remote Technology

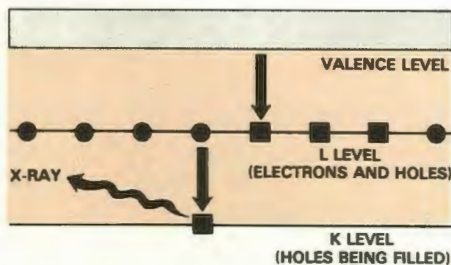
For the past five years, a major national program on nuclear fuel reprocessing systems has focused on developing advanced technology for remote-handling operations. Although the United States has lost ground to several countries in commercial reprocessing of light-water-reactor fuel, we now enjoy a position of world leadership in advanced remote maintenance techniques through work done under DOE's Consolidated Fuel Reprocessing Program, for which ORNL is the technical management center. Perhaps only France is at the same level of competence.

Although remote technology is being developed for reprocessing, its value extends to many related nuclear fields and to other nonnuclear but hazardous

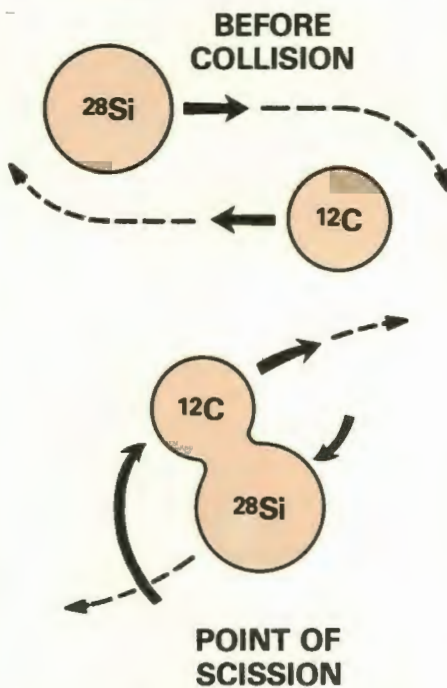
operations. For example, maintenance of future fusion-energy machines will require such systems. The radioactive cleanup and fuel-recovery operations at the Three Mile Island nuclear power plant would have been greatly helped by remote technology because certain areas in the containment shell remain too highly contaminated for direct manned operations. Dismantling chemical and biological weapons is another potential area of application.

While many facets of remote operations can be improved, the key to significant advances lies in the remote servomanipulator that we are developing to permit an operator to control a set of slave manipulator arms, located in a remote hazardous location, from a master controller in a safe operating area. Such a manipulator is equipped with force feedback, which provides "feel" to the operators, thus greatly enhancing system capabilities. Television viewing, coupled with wireless signal communication, permits complete decoupling of master and slave, although this procedure may





*In heavy-ion-induced x-ray fluorescence, the rate of electron refilling caused by the chemical environment of the target atom is seen in its x-ray signal.*



*A grazing collision of beam and target nuclei produces a long-lived, orbiting dinuclear complex.*

not be necessary for some applications. The servomanipulator must have as nearly manlike capabilities as practical, such as the ability to handle objects weighing 20 kg as well as dexterity in operating tools.

Our developments have far outclassed early models of servomanipulators, such as the Oak Ridge Mobile Manipulator built some 15 years ago; these old systems now belong to the "Model T" era because they lack force feedback and require a cable connection between slave and master. The advanced

servomanipulators are incorporated in a new Remote Systems Demonstration Facility, now in operation in a cell in the Thorium-Uranium Recycle Facility at ORNL. The work is under the direction of Melvin Feldman of the Fuel Recycle Division and William Hamel of the Instrumentation and Controls (I&C) Division.

Our development work centers on all subsystems that link the operator and the hostile work environment. We are focusing on activities that will improve reliability and develop the required wireless digital communications networks. Although the technology has some of the flavor of robotics, there are important basic differences. Generally, a robot is programmed to do specific, usually repetitive tasks such as those needed on automobile assembly lines. Servomanipulators, on the other hand, are under the real-time control of an operator who is doing a special but nonrepetitive task. The cross-fertilization of these two technologies is quite important, consequently allowing us to incorporate advances in robotics into development of tools having special application in the nuclear and hazardous fields. We are cooperating with Japan and the United Kingdom in this exciting field where the goal is to "project" humans for meaningful work in hostile environments.

#### **Automatic Noise Surveillance and Diagnostic System**

The third and final example from the technology area is the development by the I&C Division of a sophisticated system to detect abnormal conditions in nuclear power plants by recording and analyzing small variations in plant-operating conditions. A major step in qualifying this system for ultimate use in the Clinch River Breeder Reactor Plant (CRBRP) was achieved this year with

successful completion of an 18-month test at the Tennessee Valley Authority's (TVA's) Sequoyah Nuclear Plant near Chattanooga. Through pattern recognition and artificial intelligence, the system, when fully developed, will interpret noise signals to provide the operator with indications of abnormal behavior, prognoses for continued operation, and needs for maintenance. Dwayne Fry is the group leader, and Cyrus Smith is the project manager for the development, to which Ned Clapp, William Sides, Frank Sweeney, and Jim Mullens have contributed.

The ORNL system monitors the electronic signal fluctuations or "noise signatures" based on 23 plant-operating variables, such as power level, coolant flow, temperature, pressure, and vibration. These signatures are compared statistically to a baseline noise signature that reflects normal plant operation.

This is the first surveillance and analysis system designed specifically for automated long-term monitoring of nuclear power plants. When fully developed, it is expected to provide for early detection of abnormal vibrations, coolant boiling, and dissolved coolant gas in present-day pressurized-water and boiling-water reactors as well as future liquid-metal fast breeder reactors (LMFBRs).

The development, which was carried out as part of the LMFBR base technology program, began with initial tests of a prototype system at the High Flux Isotope Reactor in 1980. The 18-month test at Sequoyah's Unit 1, which was sponsored by the U.S. Nuclear Regulatory Commission (NRC) and completed in September 1982, ran through the first fuel loop and is to be followed by a three-month test during the second fuel loop—a test now under way. Also, during the



year ahead, a qualification test is planned in Hanford's Fast Flux Test Facility, the test bed for breeder reactor fuels and materials. These steps are designed to prepare the automated system for use

during the start-up and demonstration operation of the CRBRP. The development of a "generic" noise signature code based on these early tests also should provide a valuable

diagnostic tool to improve the on-line reliability and operational maintenance of currently operating nuclear plants.

## Technical Highlights:

### The Sciences

The following highlights in the physical and life sciences are not as closely related to the theme, but they reflect outstanding developments across the spectrum of ORNL programs during the past year.

#### Selective Tree Breeding

In the evaluation of alternatives to petroleum as an energy source, "woody biomass" has been recognized increasingly as a potentially important source of fuels and chemicals. In many respects, however, little more is understood today about many hardwood species and how to grow them efficiently than was known by the early American settlers.

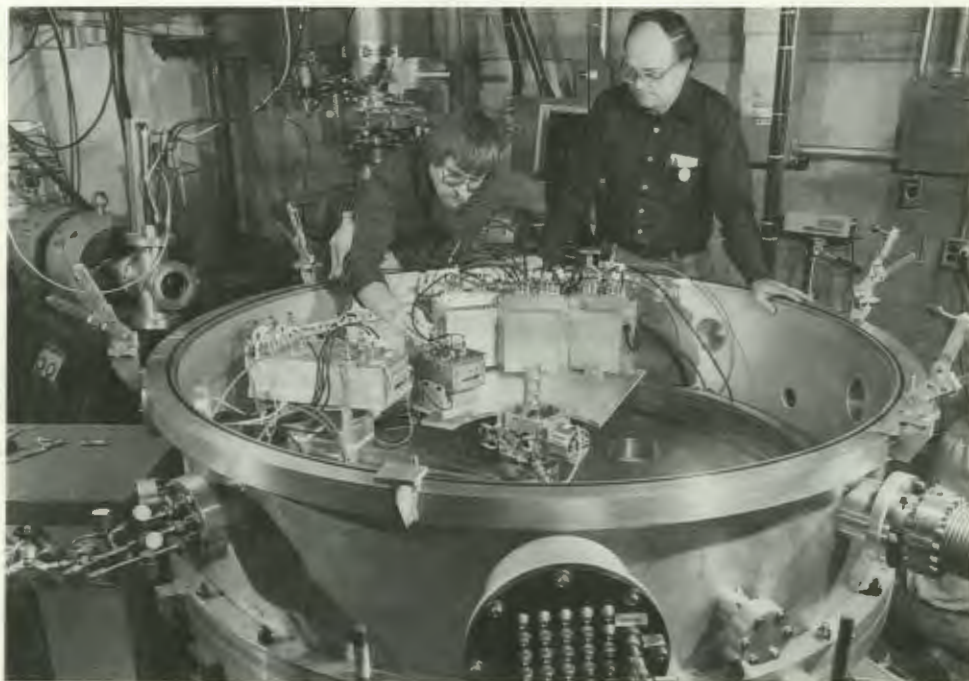
In one of its program management roles for DOE, ORNL is responsible for the Short Rotation Woody Crops Program, a six-year coast-to-coast effort combining field and laboratory research to assess and improve the growth potential of different woody

species as a specialized energy crop under a range of soil and climate conditions. The objective of the program is to provide the scientific foundation for intensive production of trees to supply more wood for fuels and chemical feedstocks. Research is being carried out under contract at 28 institutions across the country in a program managed by Jack Ranney, Janet Cushman, and Lynn Wright of the Environmental Sciences Division.

Screening studies of fast-growing hardwood species show that development of genetically improved planting stock offers great potential for long-range increases in biomass production. One key finding of the contractors is that a great deal of genetic

variability exists in most hardwood species. Genetically superior individuals show growth rates 48 to 90% greater than the average growth rate of unselected stock for species as diverse as four-wing saltbush, big sagebrush, mesquite, eucalyptus, and black cottonwood. Further, hybridizing gives faster-growing and more site-adaptable trees. Characteristics such as cold tolerance, insect and disease resistance, growth rate, and wood quality are genetically controlled yet inherited independently. This awareness of genetics makes breeding trees with the characteristics needed for specific biochemical and thermochemical conversion processes an exciting, long-term research possibility.

*Rainer Novotny, visitor from Heidelberg, West Germany, and Jim Ford, ORNL physicist, align detectors for an experiment using the Holifield Heavy Ion Research Facility. In this work, silicon beams from the Holifield accelerator enter the 1.6-m diam scattering chamber (right), where they strike a carbon target (center) and initiate a nuclear reaction. Reaction products are detected in the avalanche detectors (upper center) and in the two ionization chambers (left center). Correlations observed among events recorded in coincidence in the various detectors reveal that the beam and target nuclei interact to form a relatively long-lived, orbiting dinucleus system.*





Hardwoods have emerged as principal candidates for intensive cultivation and short rotation on certain sites because most species sprout from the stump after cutting, thus eliminating the need to replant and increasing second-generation growth because a root system already is established. Many of the selected hardwoods also grow more rapidly in the first few years than do softwoods such as pine. It is hoped that the new knowledge will allow us ultimately to produce wood efficiently on land that is marginal for agriculture.

### Reducing Bioeffects of Coal Liquids

The potential environmental and health effects of crude, coal-derived synthetic fuels are considered to be more severe than those of petroleum crudes. Investigating treatment processes that promise to

reduce the bioeffects of coal liquids has been a task of a cooperative Fossil Energy/Life Sciences Synthetic Fuels Programs study involving the Analytical Chemistry, Biology, Environmental Sciences, and Chemical Technology divisions at ORNL. Coordinators of their respective divisional contributions are Wayne Griest, Peter Witschi, Jeffrey Giddings, and Jerry Klein.

These researchers have been studying the effects of hydrotreatment, a process used in petroleum refining in which oil is heated under hydrogen pressure in the presence of a catalyst. Blends of middle and heavy distillates from three coal-liquefaction processes have been water washed and subjected to different levels of hydrotreatment. ORNL's role has been to characterize the chemistry and bioactivities of the treated samples.

Our results show that regular changes in the properties of the sample occur with increasing levels of hydrotreatment: the sample becomes more volatile, less dense, and less viscous. Its heteroatomic content (sulfur, nitrogen, and oxygen) as well as the presence of potentially carcinogenic polycyclic aromatic hydrocarbon (PAH) compounds in it decrease as hydrogen is incorporated into it. These gross changes are reflected in more detailed measurements.

For example, the weight percentages of both the ether-soluble acid and ether-soluble base fractions as well as the PAH fraction decline by factors of 10 to 20. Phenol, a toxic component, drops even more precipitously, as does the carcinogen benzo[a]pyrene. Similar decreases are noted for mutagenic, nitrogen-containing aromatics. These data are supported by the results of multiple bioassays, which indicate that the biological activity of the sample decreases with an increase in the severity of hydrotreatment. On the

other hand, washing the product in water before hydrotreatment does not decrease its biological activity. Our conclusion, therefore, is that hydrotreatment is a very useful refinery process for upgrading coal liquids.

We are exploring additional ways of reducing bioactivity. Our findings so far indicate that methods such as acid washing, thermal distillation, solvent extraction, and charcoal or power plant hopper-ash adsorption are potentially promising in removing mutagens. Whether these methods also can remove other types of hazardous compounds—toxicants, teratogens, or carcinogens—from synfuels products remains to be seen in further investigations.

### Silicon Melting During Laser Annealing

In the late 1970s, ORNL solid state physicists developed the technique of laser annealing to remove damage in silicon semiconductors caused by ion implantation of dopants. Among the desirable effects, besides damage removal, are dopant incorporation and surface cleaning. The laser-annealed, ion-implanted silicon has been used to make experimental solar-electric cells of potentially high efficiency.

These positive results have led to considerable speculation about what structural and phase changes occur in the semiconductor during annealing. One theory was that the pulses of laser light caused the crystalline surface of the silicon to convert momentarily to a "cool plasma fluid" no warmer than 400°C. The other theory, developed at ORNL, held that the silicon surface melts, thus losing its crystalline structure temporarily as the temperature reaches the melting point of 1410°C.

To answer the question, Bennett Larson, C. W. (Woody) White, and



Ken Valentine, Manfred Kopp, George Guernant, and James Harter (left to right) display the ultrahigh-sensitivity fission counter that they developed. This neutron detector and its associated instrumentation were developed for neutron flux monitoring in the Clinch River Breeder Reactor Plant.



*Zane Egan observes fluorescence from a sample in a centrifugal analyzer. The intensity of the fluorescence indicates the amount of activity of the mixed function oxidase (MFO) enzyme in livers of animals that have been exposed to polycyclic aromatic hydrocarbons (PAHs). These potentially carcinogenic compounds are present in coal-derived products. It is hoped that measurements of MFO enzyme activity can be made on body fluids and skin to determine the extent of human exposure to potentially hazardous compounds in coal products.*

Thomas Noggle of the Solid State Division have measured for the first time silicon temperature profiles during the actual split-second annealing. The required nanosecond resolution has been achieved by using synchrotron x-ray pulses to monitor lattice thermal expansion with three orders of magnitude better time resolution than previously attained. This monitoring was made possible by synchronizing the firing of the 15-ns ruby laser (annealing) pulses with 0.15-ns probing x-ray pulses from the Cornell High Energy Synchrotron Source. Measured 20 ns after laser pulsing, the lattice temperature profile shows that (1) the temperature of the silicon reaches the melting point (1410°C), (2) an approximately 0.4- $\mu\text{m}$ -thick melted layer is present, and (3) during resolidification the temperature difference is driven by a temperature drop of a 1000°C in a  $\mu\text{m}$ .

The broader significance is in the method itself, which for the first time demonstrates the combination of pulse intensity and resolution needed to obtain real-time structural information with synchrotron X rays, thus opening a whole new area of science on fast transient phenomena in solids. This tool promises new understanding of many processes such as crystal regrowth and the physical details of melting.



### Resonance Ionization Mass Spectrometry

As an outgrowth of the ORNL-developed resonance ionization spectroscopy (RIS) technique, which was used in the "one-atom detection" experiment in 1977, the capability for resonance ionization mass spectrometry (RIMS) has now been developed by David Donohue, Jack Young, and David Smith of the Analytical Chemistry Division. This new analytical technique, which is designed to facilitate measurements for the accountability and safeguarding of special nuclear materials, combines two spectroscopic methods: RIS, in which atoms energized with carefully tuned "resonant" laser light lose electrons, and mass spectrometry, in which the resultant ions are separated and detected according to their mass.

This combination, RIMS, provides an extra measure of selectivity so that elements that differ in atomic number and chemical properties but have the same mass (isobars) can be distinguished and measured in the presence of each other. The technique is based on forming a cloud of sample atoms, into which focused laser light of a chosen energy is directed. These photons are absorbed only by atoms of a given element, thus resulting in

promotion of an electron to a quantum-allowed intermediate level. Absorption of a second photon then ionizes each atom. The ions of the one element are extracted into a mass spectrometer which separates them according to mass and counts them.

Isobaric interference from neighboring elements or molecular species is virtually eliminated—a major improvement over the conventional method of thermal ionization mass spectrometry. The elements that are most easily ionized by RIMS include many of the rare-earth and actinide series. To date, substantial work has been performed on neodymium, samarium, and europium, and very promising results also have been obtained for plutonium.

Besides its insensitivity to isobaric interference, RIMS has other important advantages: (1) it eliminates the need for time-consuming chemical separation, (2) it does not require as high a temperature as does mass spectrometry, and (3) it is sensitive to microgram-size quantities of material. The high elemental selectivity and sensitivity appear ideally suited to measuring the isotopic composition of trace elements in nuclear, geological, or environmental samples.





*This loop at the East Mesa, California, geothermal test site was used to test fluted tubes designed at ORNL. These tubes were tested in a condenser ten times the size of the pilot-plant condenser at DOE's Raft River, Idaho, geothermal test site, where one of ORNL's high-performance tubes was first evaluated.*

### Heavy-Ion-Induced X-Ray Fluorescence

The chemical nature and bonding of the elements that make up alloys and ceramics are a key to a more fundamental understanding of materials. A technique being developed to better characterize these materials is an x-ray fluorescence method that uses energetic heavy ions for excitation. This method, the product of a cooperative effort by Thomas Rosseel, John Dale, Lester Hulett, and Jack Young of the Analytical Chemistry Division and Herbert Krause, Subramanian Raman, and Randall Vane of the Physics Division, shows promise especially for answering questions about the chemical environment of an element in a bulk material.

Heavy-ion bombardment of targets at intermediate velocities (1 MeV/amu) produces a higher degree of multiple ionization than does either electron bombardment

or photoionization. When the multiply ionized target atom relaxes, it emits a series of prominent x-ray satellite lines that correspond to states of multiple electron vacancies. It has been shown that, depending on the chemical environment of the emitting target atom and the velocity of the projectile, these lines vary in their intensity.

The analytical potential of this method has been evaluated on a variety of substances containing the same element. For example, the x-ray fluorescence produced by bombarding a series of molybdenum alloys with energetic chlorine ions from the EN-tandem Van de Graaff accelerator results in different intensity distributions for each alloy. Because the intensity of the observed fluorescence depends upon the rate of electron vacancy refilling, a change in the intensity indicates a difference in the density or distribution of the valence electrons of the element of interest. This change means that the technique is probing the chemical environment of the element. Based on these results, a collaborative effort is under way with the M&C Division to explore the application of this method to the examination of the valence characteristics of long-range-ordered (LRO) alloys.

### Orbiting of Light Nuclei

Experimental evidence for a significant new mode of interaction between colliding nuclei—a phenomenon called orbiting—has been reported by Dan Shapira, Karl Erb, Y.-d Chan, James Ford, Jorge Gomez del Campo, and Reiner Novotny of the Physics Division. The orbiting phenomenon occurs when light nuclei such as neon-20 and carbon-12, aluminum-27 and oxygen-16, or silicon-28 and carbon-12 approach each other in a near-grazing collision. The two ions tend to clutch and form a long-lived

dinuclear complex—a moleculelike system that rotates and survives long enough so that, when separation eventually occurs, a memory of the incident beam direction effectively has been lost. As a consequence, reaction products associated with orbiting are emitted with equal probability at all angles to the incident beam direction. The most dramatic effects are observed for products emitted opposite to the beam direction (back-angle scattering) because reactions having time scales shorter than that of orbiting generally exhibit greatly suppressed back-angle yields.

At low and medium energies, such colliding nuclei are likely to fuse into a single distorted nucleus called a mononuclear complex or compound nucleus. However, in earlier experiments involving collisions of heavier ions such as argon and lead, a similar process falling short of fusion was observed: a dinuclear complex was formed in which ions revolved briefly around each other in a forward motion before they flew apart. The question recently asked by this group is whether orbiting might be an equally or even more significant mode of interaction for light nuclei in higher-energy collisions.

By measuring the excitation energies of the fragments and analyzing details of the back-angle scattering, the physicists deduced that orbiting not only occurs but also that it lasts much longer in collisions of light nuclei than it does in collisions of heavier ones. Furthermore, orbiting becomes more pronounced as the energy of the incident beam is increased.

More studies involving collisions of these and other ions at higher energy are to be performed at the Holifield Heavy Ion Research Facility to probe further the nature and limits of this new and interesting reaction mode.



## Technical Highlights:

### The Technologies

This final group of highlights has been selected from the technology areas of our program.

#### Ultrahigh-Sensitivity Fission Counter

This year an important advance in nuclear technology has been the development of an ultrahigh-sensitivity fission counter, which will be used to measure the number of neutrons produced by fissioning uranium and plutonium atoms at the CRBRP. This unit, which was developed by a team headed by Ken Valentine and composed of Manfred Kopp, George Guerrant, and James Harter, all of the I&C Division, is superior to conventional boron trifluoride counters in these ways: it is 50 times as sensitive, exhibits 100 times as much tolerance for gamma radiation, and can operate at higher temperatures (260°C vs 100°C). It is designed to operate reliably in these high-temperature, high-radiation environments for up to 30 years, compared with an expected life of two years for conventional counters exposed to full-power neutron intensity.

In the CRBRP, the new counter will be used to monitor neutron fluxes in regions outside the vessel. Other potential applications are subcriticality measurements in future fuel reprocessing plants, light-water-reactor control systems, and diagnostics for fusion-energy devices.

*Jerry Strandberg studies how well cellulosic materials can be broken down by anaerobic bacteria in this bioreactor. Anaerobic digestion is a promising technology for reducing the volume of radioactive cellulosic and animal wastes. Results from the ORNL bioreactor will be used to guide further process development work in a larger 70-L bioreactor.*

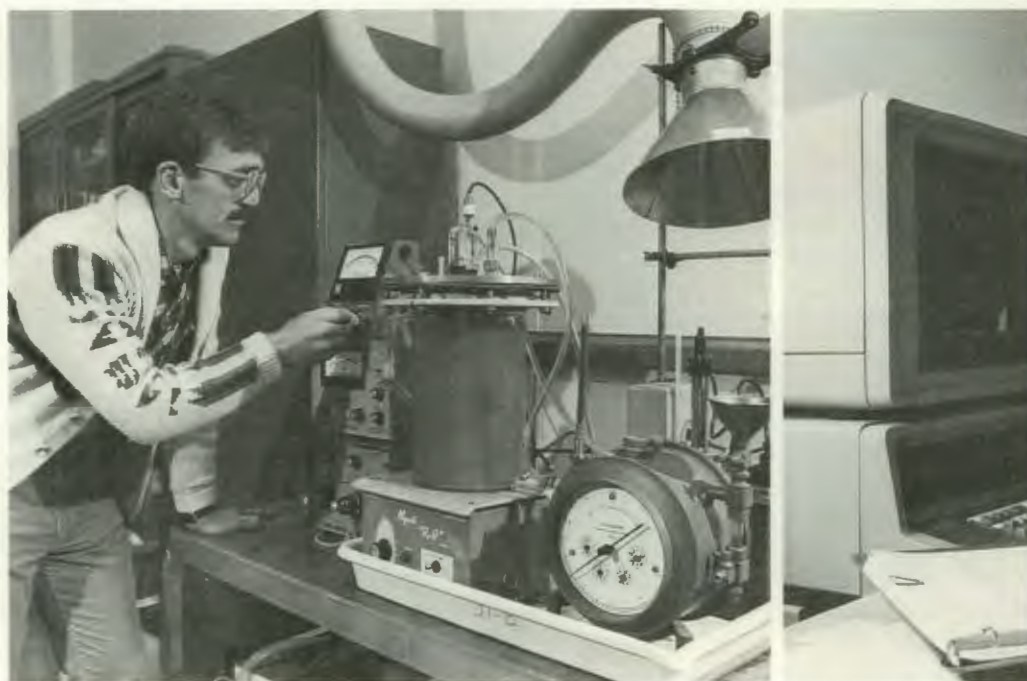
Fission counters, which measure the neutron flux levels of nuclear reactors, consist of gas-filled chambers containing plates that are coated with a thin layer of fissionable uranium-235. When a neutron strikes the coating, fission occurs, and the fission fragments ionize the gas in the chamber, thus producing an electric charge that can be detected and counted electronically.

Although conventional counters are sufficiently sensitive for full-power operation, the ultrahigh sensitivity of the new device will be especially valuable during the early start-up of reactor operations when fluxes are relatively low and interference effects have made fission counting difficult. The interference is caused mainly by the alpha activity inherent in the uranium coating of the gas chamber plates. Superpositions of many small alpha pulses appear as neutron pulses, thus reducing sensitivity. In practice, this

reduction in sensitivity has not hindered in-core measurements, but it has been troublesome for measuring the much lower neutron flux outside a reactor vessel.

Efforts to improve sensitivity depend largely upon increasing the plate collection area. In the ORNL concept, this increase is achieved by a radically different design that uses curved or convoluted plates. Further, the amplitude of neutron pulses has been increased by use of a "fast gas" consisting of 80% argon and 20% carbon tetrafluoride that provides extremely rapid electron collection and, hence, pulses of very short duration. The fast gas itself is a contribution of the atomic, molecular, and high-voltage physics group led by Loucas Christophorou of the Health and Safety Research Division.

Through a technique known as "time interval discrimination," which uses delay-line circuitry, the group greatly reduced alpha interference. Coincidence logic is





used along with conventional pulse amplitude discrimination to count the neutron charges without interference.

The development is an important accomplishment of the LMFBR base technology program. The aim of further work in the CRBRP-supported test of our fission counter is to make our counter even more sensitive and reliable.

### Personnel Monitoring Technology

Among the potential health hazards of coal-liquefaction processes is a class of suspected carcinogens known as PAHs. The PAHs, which cause cancer in experimental animals, are common in coal tars.

One new approach to personnel monitoring has been to detect possible human physiological response to PAH exposure, as measured by a sensitive and specific biochemical indicator. This work has been carried out by Carl Burtis, Zane Egan, Norman Lee, William Bostick, and Jack Mrochek of the Chemical Technology Division in collaboration with

Michael Holland and John Kao of the Biology Division.

PAHs are metabolized by the mixed-function oxidase (MFO) enzyme system. Because the carcinogenic potential of reactive PAHs can be either diminished or enhanced by the metabolic activity of the MFO system, the amount of MFO activity induced by a PAH is considered an indicator of the toxicity of the PAH. The MFO activity is determined kinetically by measuring the rate of formation of a highly fluorescent material, resorufin, produced by the oxidation of the 7-ethoxyresorufin substrate.

So far, these tests have demonstrated a dose-response relationship between the MFO activity and the exposure of test animals to various materials, including coal liquids. In a study of a series of natural and synthetic petroleum, the magnitude of induction of MFO activity of each test material corresponded to its previous ranking as a carcinogen and mutagen. In other words, a coal liquid ranked as highly potent in causing cancer and genetic mutations in animals was found to induce also a large amount of MFO activity.

Although the measurements have been limited to samples from mouse-liver microsome, they are to be extended to human body fluids and skin. Because of the decreased amount of the MFO enzyme system present in the body samples, an argon laser has been interfaced to a centrifugal analyzer, thus making the fluorometric measuring system at least 100 times more sensitive. With this gain, it is expected that the system will be able to monitor, from whole blood samples, the physiologic response of plant

personnel to potential carcinogenic or mutagenic compounds that may arise in the synthetic fuels industry.

### Anaerobic Digestion of Radioactive Cellulosic Wastes

One of the solutions to our waste-processing and disposal problems often is quite literally to "bug" them. Biotechnology has provided the tools for finding microorganisms whose natural functions can be adapted to achieve a desired result, such as the breakdown of various potentially hazardous waste products or the isolation and recovery of materials of value. Now, a group in the Chemical Technology Division has applied the biological process of anaerobic digestion to radioactively contaminated cellulosic materials, such as paper and cloth, to convert them to water-soluble forms. Anaerobic digestion breaks down complex chemical structures through the action of microorganisms, thereby achieving a volume reduction of the wastes while putting the radioactive contaminants in a more convenient (i.e., liquid) form for disposal.

Terry Donaldson, Jerry Strandberg, and Frank Harrington have developed and analyzed the economics of a preliminary process design. Their results indicate not only that the process is technically feasible but also that costs would be comparable to compaction and burial—and much less than incineration. The process also appears to have an unusual advantage: it can be scaled down economically for use at small facilities.

The water-soluble wastes produced in the process could be treated at existing ORNL liquid radioactive waste facilities and disposed of by hydrofracture. Methane (natural gas), which is produced during anaerobic digestion, could be collected for its

*Alan Witten and Frank Kornegay (in back) use computer modeling to work out proposed strategies of pollution control over large regions.*



*Paul Haubenreich, manager of ORNL's Large Coil Program, introduces Professor Ko Yasukochi of Japan's Nihon University during the November 29, 1982, dedication ceremony at ORNL's Fusion Energy Division. The ceremony celebrated the arrival of the Japanese superconducting magnetic coil and completion of the Large Coil Test Facility for the test of two coils scheduled for this summer. Six coils (three contributed by the United States and one each by Japan, West Germany, and Switzerland) will be tested in a toroidal array in the summer of 1984.*

energy value. After further bench-scale tests, a full-size facility will be designed. Such a facility could benefit us by reducing the amount of land needed for burying low-level solid wastes.

### Advanced Toroidal Facility

Progress toward the goal of practical, power-producing fusion reactors is the product of advances in physics understanding and in key supporting technologies (e.g., superconducting magnets and heating and fueling devices) and of innovative approaches to magnetic confinement of fusion plasmas. Current efforts are aimed at designing and building devices that embody the characteristics ultimately desired in fusion reactors (e.g., steady-state operation, accessibility, and maintainability).

An important element of our work this year as part of the national fusion program has been the design of a new magnetic confinement experiment, the "torsatron." Called the Advanced Toroidal Facility (ATF-1), this device would replace the present ORNL tokamak, the Impurity Study Experiment (ISX-B). The torsatron differs from the tokamak in that the helical field required for fusion plasma confinement is provided entirely by external coils rather than relying partly on current in the plasma. This feature offers the potential for steady-state operation



(because recirculating power to the plasma is not needed to maintain the confinement geometry) and eliminates instabilities caused by the plasma current, thus making the torsatron an attractive reactor candidate. This difference between the two principal members of the toroidal confinement family also allows torsatron studies to clarify the physics of tokamak behavior. In addition, the torsatron and related stellarator concepts have spawned an array of interesting possible designs from which to select the "best" device and even to combine with the tokamak in a hybrid device.

As with other fusion devices, a key issue is the level of beta—the ratio of plasma pressure to magnetic field pressure—which can be attained before the onset of instabilities. This year a major advance has been the development of a torsatron configuration that is predicted to exhibit increasing stability as beta increases. Key contributors have been James Lyon, Jeffrey Harris, Thomas Jernigan, Benjamin Carreras, James Rome, and John Sheffield of the Fusion Energy Division and Brad Nelson and Ray Johnson of the UCC-ND Engineering Division. The especially favorable configuration was found when analyses made with new theories and computer

codes showed that a much tighter-aspect-ratio torus (i.e., a fatter, more compact doughnut) is more attractive than had been previously thought. A resulting "window" was found in which the stable beta value exceeds 7.5%, which is competitive with the better predictions for tokamaks and certainly high enough to permit interesting torsatron reactor designs.

The beta values predicted for ATF-1 greatly exceed those for existing devices of the same family in Germany and Japan. On the basis of these findings and many related analyses, ORNL has proposed to build a new device that has received excellent reviews within the fusion community. Funding for the ATF-1 has been approved by DOE's Office of Fusion Energy.

Not only is the design itself a significant step but so also is the role played by computer-aided design and computer-aided drafting (CAD/CAM) as a research tool. Because of the complex geometry of the torsatron's magnetic coils and the very tight tolerances to which they must be built (one part in 1000), this capability was essential to the project. In one of the CAD/CAM systems used, a mathematical function describing the center line of a torsatron



winding is programmed into the computer, which generates the coordinates of points along the winding and displays the points, properly connected, on the screen. The image can be manipulated by zooming in or out, rotating, removing lines, and dimensioning as part of an interactive process. Another system has generated color pictures of the overall design. The application of computerized design ably supports the conceptual and theoretical innovations planned for fusion R&D.

### High-Performance Heat Exchanger

As part of the Laboratory's desalting program in the 1960s, vertical fluted-tube evaporators and condensers were developed. These fluted tubes enhance condensation heat-transfer coefficients by allowing surface-tension forces to produce very thin liquid films on the curved surface at the crest of the flutes, while the troughs provide a convenient drainage path for the condensate. Thus, the thinning of the condensate films reduces the resistance to heat flow, or increases the heat-transfer coefficients, on the crests of the flutes. Similar tube surfaces (e.g., 1-in. diam tubes with 60 axial flutes on the outer surface) have been evaluated for use with working fluids other than water for application in geothermal binary power cycles and waste heat recovery systems. This work has been carried out by John Michel of the Energy Division, Richard Murphy of the Engineering Technology Division, and George Llewellyn of the UCC-ND Engineering Division.

Previously, tests with single vertical tubes of some 30 different geometries with up to 7 different fluids (e.g., hydrocarbons, ammonia, and fluorocarbons) had been done. Recently, at DOE's Raft River,

Idaho, geothermal test site, Michel and his colleagues evaluated one of the highest-performance tubes for use in condensing isobutane vapor (the working fluid in this geothermal power cycle) in a pilot plant condenser.

Field-test results have confirmed the laboratory data by showing that condensation coefficients for fluted-tube condensers are about six times as high as those for smooth tubes and that the performance of the fluted tubes is more than twice as high as that of conventional condensers. These results suggest that only half the number of tubes is required; thus, the cost of the heat exchanger is reduced considerably, despite the added cost of the enhanced tubes.

In low-efficiency power cycles and waste-heat recovery systems, such as geothermal power plants, the waste-heat rejection system is usually the largest and most costly component. Such cost reductions, therefore, contribute significantly to ultimate feasibility. The application of fluted-tube designs also may prove to be important in water-source heat pumps in which the refrigerant heat-transfer resistance dominates the overall resistance.

### Mass and Heat Transfer in Absorption Fluids

The practical goal of this research is the development of new technology, such as improved absorption heat pumps, to boost the temperature of industrial waste heat so that it can be reused in many industrial processes. Harry Arnold, Gershon Grossman, Wilbur Huntley, and Horacio Perez-Blanco of the Energy Division have worked on several facets of absorption heat pump technology.

Mass-transfer processes—in which one component is separated from or combined with a two-component mixture—are employed

in absorption machines to separate the refrigerant from or to absorb it into the working solution. Because mass- and heat-transfer rates determine the physical size of an absorption machine, it is important to know mass- and heat-transfer coefficients, which allow the prediction of mass- and heat-transfer rates at given conditions. Therefore, before industrial absorption machines can be designed, what is needed is the ability to predict mass- and heat-transfer rates under conditions that might be important for industrial applications.

No precedent exists, however, for determining these coefficients analytically for simultaneous mass and heat transfer. In the usual applications, the mass transfer is ignored because it is deemed negligible compared to the heat transfer, or, conversely, the heat transfer is ignored when mass transfer is considered dominant. In absorption heat pumps, however, because of the nature of the working fluids, both processes are intimately coupled; thus, neither can be assumed negligible.

Perez-Blanco and Grossman worked out an analytical solution for the theoretical case of the mass- and heat-transfer process during absorption of a vapor into a liquid film. Their model shows how much surface length (residence time) is needed during the absorption process for equilibrium to be reached. Manufacturers have solved this problem analytically for the chillers they build, but it has not been solved before for the higher temperatures in absorption heat pumps.

A resulting ORNL invention specially designed for recovery of low-grade waste heat is an adiabatic absorption stage that provides the extra surface to force the fluids to equilibrium before heat is extracted. By this simple action, the temperature boost that



*The new Hydrofracture Facility received its first injections of resuspended sludge from the World War II gunite tanks, which were retired upon completion of ORNL's Intermediate-Level Liquid Waste System.*

can be obtained from the heat pump is maximized. Tests of an absorption machine that incorporates this feature have verified the predicted benefits of the added adiabatic stage. This is part of a total program of analytical, experimental, and proof-of-concept investigations for industrial absorption heat pumps. The extensive mass- and heat-transfer data will be used to confirm the viability of the analytical models as design tools.

This development paves the way for designs of heat sources matched to the needs of the paper, textile, and other selected industries that reject large amounts of heat within a range that could be boosted economically with the new heat-pump technology. Companion studies show that perhaps 20% of the heat rejected across all industrial sectors in the 40–70°C range could be used productively with this new technology.

### **Pollution Control Strategies**

A potential source of air pollution, especially in the northeastern United States, is the conversion of oil-burning power plants to coal-fired stations. As part of a study by Alan Witten and Frank Kornegay of the Energy Division, air quality models have been developed to quantify the impacts of the expected variability in sulfur dioxide emissions from the converted power plants. Witten, Kornegay, and Ed Long of the Computer Sciences Division developed two models—one for addressing local impacts from a single facility and the other for



assessing regional impacts from the operation of multiple facilities.

The multisource model, in particular, with its specially developed computer graphics program for displaying air quality statistics, has provided a valuable tool for the development and evaluation of pollution control strategies. Applied to the Northeast, it was found that air quality standards could be met over an entire study region through judicious selection of a small number of facilities for installation of pollution abatement devices. Both the single and multisource models also are being used by TVA in our own area.

This approach to air quality modeling could have a positive impact on the air quality regulations imposed under the Clean Air Act. In a cooperative project with selected utilities and with Phil Walsh and Elaine Zeighami of the Health and Safety Research Division, Witten and Kornegay investigated the benefits of a hypothetical regulatory change. They found that the flexibility afforded utilities by this change could result in capital and operating cost savings for flue-gas desulfurization equipment in excess of 2%—representing more than \$400 million annually if the

approach were applied on a national basis. More importantly, the regulatory change would cause no quantifiable change in health effects and would reduce total sulfur dioxide emissions by more than 10%. These hypothetical rules could offer utilities and industries economic incentives rather than economic penalties for reducing sulfur dioxide emissions. The implementation of new rules not only would provide a cost-effective means to reduce regional pollutant levels but also could result in some decrease in acid precipitation.

### **Summary and Outlook**

Each year, in reviewing the many excellent technical projects from which highlights for this address are selected, I find new evidence that the Laboratory is an institution of unquestionable vigor, proven accomplishment, and outstanding intellectual strength. This year I can add with pleasure that in 1982 that judgment has been confirmed several times over by independent groups of appraisers, including some of the nation's most eminent technical leaders from all sectors.

The "State of the Laboratory" address gives me an opportunity to cite not only technical highlights





Tourists leave ORNL's new Visitor Overlook, which was built in time for the 1982 World's Fair.

but also other important milestones in our year's work. One of these is the Laboratory's continuing exceptional performance in the area of job-related safety. This year we were recognized by the National Safety Council for having the best record among R&D laboratories and for placing first in its chemical division. In addition, we received the first gold award presented to a Union Carbide facility for safety performance because of our more than 16 million employee hours on the job without a lost-time accident. Although we had one lost-time accident in 1982, in June, that now stands as the only one over a period of more than 2.5 years—or nearly 23 million employee hours on the job—a remarkable record!

That is more, however, than an institutional record. It is, above all, a record of individual attention and commitment to safe job behavior and following established safety practices. The winner is not just ORNL, the institution, but all of us who, by making safety a part of our jobs, have avoided the personal loss and consequences of a serious accident. As you know, a two-fold challenge is before us: to continue this outstanding on-the-job performance and, at the same time, to extend it into the off-the-job

hours where, in a statistical sense, the likelihood of serious injury is now about 30 times greater than that on the job.

Another record of which we can be equally proud, as measured by an external standard, is the six IR-100 awards presented to ORNL this past year. These awards are given by the magazine *Industrial Research & Development* for the year's 100 most significant new technology advances. In 1982 we tied General Electric and Dow for having won the highest number of awards for any single organization. With a total of 31, we have received more IR-100 awards than any other DOE laboratory.

During the 1982 World's Fair in Knoxville, we welcomed what may be a record number of visitors to ORNL. A related milestone in facility development was the completion of the Visitor Overlook, which is located on the hillside across from the main entrance to the Laboratory. This handsome structure, with a commanding view of our site, will be an asset to the Laboratory staff and visitors for many years to come.

In June we dedicated a major experimental facility for the Consolidated Fuel Reprocessing Program, the Integrated Equipment Test (IET) facility. The IET

combines a Remote Operations and Maintenance Demonstration of major front-end nuclear fuel reprocessing components with an Integrated Process Demonstration of the chemical stages that follow.

In our on-site waste management activities, the first "hot" injection at the new Hydrofracture Facility took place in June. That injection, and three others that followed this year, disposed of some  $1.7 \times 10^6$  L ( $6.5 \times 10^5$  gal) of resuspended sludge from the World War II gunite tanks, which are to be retired now that the upgrading of our overall Intermediate-Level Liquid Waste System has been completed.

Finally, in late November, ceremonies marked the arrival of the Japanese superconducting magnet coil, which is to be tested over the next few years in the \$36-million LCTF. This is the first of six coils—three being built by U.S. firms and three by participating international groups—which are to be tested here. The project will be a key step in the progress of one of the most important technologies for the development of magnetic fusion energy.

## Looking Ahead

Looking ahead to 1983, we expect a continuation of many trends observed and commented on earlier. We anticipate, under Secretary Hodel's leadership, that much of the uncertainty that has surrounded DOE's future will diminish in its impact on program activities. We also expect that many of the difficult substantive issues of our energy program will be addressed by DOE and Congress (e.g., the pace of natural gas



deregulation, continued funding for the CRBRP, and the appropriate size and direction of our national effort on synthetic fuels).

We also anticipate some positive actions resulting from the recommendations of the Energy Research Advisory Board's Multiprogram Laboratory Panel. Specifically, we hope that consideration will be given to those steps designed to provide more flexibility to the laboratories in carrying out their energy R&D missions and those designed to limit some of the more troublesome reporting and administrative requirements that reduce our effectiveness.

In assessing the outlook for energy, we must be aware that the national budget dilemma will continue to exert strong pressure on all federally supported programs, including those in the energy-related sciences and technologies. Even with the recognition of the potential importance of these areas in restoring national economic health, we must be aware that no area of the federal budget will be immune from close scrutiny in the years just ahead.

The transition to a new contractor will take a definite shape during 1983, starting in April with the issuance of a formal request for proposals. A four-month period will follow in which contenders will have an opportunity to develop and submit their proposals.

Finally, there will be new opportunities for us to strengthen our interactions with users of ORNL facilities throughout the academic and industrial research communities as these user-oriented activities grow and develop. In cooperation with TVA and the University of Tennessee, we also will have the opportunity to support and assist in the planning and conceptual development for the

proposed Tennessee Technology Corridor.


In our planning activities, we are proposing new initiatives in three areas where the technical opportunity, ORNL resources, and national needs suggest that expanded or more focused efforts can be highly productive. One of these initiatives is a proposed Center for Surface Modification Research, which would build on the high-quality contributions and many effective outside interactions that have developed in the solid-state physics programs. We see much promise in the technological advances that have resulted from such techniques as ion-implantation doping and pulsed-laser annealing. Through a designated research center and a formal users' program, we can further increase the capabilities for and physical understanding of surface modifications that confer special properties such as conduction, hardness, and corrosion resistance.

Another initiative that we are proposing would explore aging effects in nuclear power plants. As many of the nation's first-generation nuclear power reactors reach middle age, their equipment and systems can be expected to start degrading because of the sustained exposure of the equipment and systems to harsh operating environments. The safety issues related to this degradation will need special attention. Our goal will be to determine corrective measures and design improvements that would extend the design lifetimes and enhance the availability of nuclear power plants.

Finally, a third new initiative will be in the previously mentioned area of remote control engineering for remote maintenance. Our goal is to apply many of the impressive new technologies developed here for fuel recycle applications to a much broader range of operating environments and needs. As we

have noted, new technology is making it possible to adapt human sense capabilities (sight, sound, and feel) used in small hot-cell systems to much larger areas and production-scale facilities.

## Conclusion

The quality of the work presented here emphasizes to me once more the special contributions of many dedicated and talented people on whom our success as an institution depends. We draw both on the strengths and creative output of outstanding individuals and on the special kind of synergism made possible in a place where the very nature of the tasks before us is complex, interdependent, and interdisciplinary in character—therefore involving many interactions among our own people and guests and visitors from the outside. The quality of these interactions and of the contributions that result is widely recognized in the objective assessments of many groups of our peers. I am optimistic about our future because I know we can count on the contributions of people who have been responsible for such a distinguished record in the past. I extend my best wishes to all of you for continued success and accomplishments of the kind for which ORNL has been so justly recognized. 





## take a number

BY V. R. R. UPPULURI

### To Pool or Not To Pool!

People who use statistics often group their data to better understand the significance of their numbers. Such "pooled" data, however, may be misleading. The following example discussed by D.V. Lindley and M.R. Novick in the March-April 1981 issue of the bimonthly journal *Annals of Statistics* shows clearly how pooled data may suggest a conclusion opposite from that based on unpooled information.

Consider an experiment in which 40 patients are given the same treatment and 40 persons who are not treated are assigned to a control group. If 20 of the treated individuals recovered and 20 did not recover, the recovery rate for treated patients is 50%. If 16 of the 40 individuals of the control group recovered, the recovery rate for the control group is 40%. Because the recovery rate (50%) for patients receiving the treatment exceeds the recovery rate (40%) for the control group, the obvious conclusion is that treatment is preferable to nontreatment.

The pooled data for both males and females are presented in Table 1.

**Table 1. Pooled data<sup>a</sup>**

	Recovered	Not recovered	Total
Treated	20	20	40
Control	16	24	40
Total	36	44	80

<sup>a</sup>Recovery rates under treatment and control are 50% for the treated group and 40% for the control group.

However, when these data are also categorized by sex, a different conclusion emerges. This unpooled information for males and females is given in Tables 2 and 3, respectively.

**Table 2. Males<sup>a</sup>**

	Recovered	Not recovered	Total
Treated	18	12	30
Control	7	3	10
Total	25	15	40

<sup>a</sup>Recovery rates for males are 60% for the treated group and 70% for the control group.

**Table 3. Females<sup>a</sup>**

	Recovered	Not recovered	Total
Treated	2	8	10
Control	9	21	30
Total	11	29	40

<sup>a</sup>Recovery rates for females are 20% for the treated group and 30% for the control group.

The tables show that for both sexes the recovery rate for each control group is 10% higher than it is for the associated treated group. Thus, the conclusion appears to be this: what holds true for males and females does not seem to apply to the population as a whole.

This phenomenon, in which pooled data and unpooled data suggest entirely different conclusions, is known as Simpson's Paradox. Many epidemiologists are aware of this phenomenon and adjust their data accordingly.

### Palindromes

An integer that reads the same in both forward and reverse order is called a "palindrome." For example, integers such as 101 and 6996 are palindromes. What is a systematic method of generating palindromes?

Take an integer such as 192 and reverse its order to obtain 291. Add both numbers ( $192 + 291 = 483$ ), reverse the order of the sum (483) to get 384, and add both numbers ( $483 + 384 = 867$ ). Continue this process to obtain the palindrome 6996:

$$867 + 768 = 1635 \rightarrow 1635 + 5361 = 6996$$

It has been conjectured that every integer will eventually produce a palindrome if the above procedure is followed; however, in some cases, the process may require a large number of steps.



Dick Hahn came to ORNL in 1962 after completing a postdoctoral appointment at Brookhaven National Laboratory. He was educated in New York City, where he graduated from the science- and math-oriented Stuyvesant High School, and he went on to earn a B.S. degree at Brooklyn College and M.A. and Ph.D. degrees in nuclear chemistry and physics at Columbia University. He joined the Transuranium Research Laboratory when its doors first opened in 1967 and has been its director since 1974. Over the years, he has been involved in several areas of research, ranging from nuclear reaction studies to chemical spectroscopy to neutron diffraction. Hahn is the codiscoverer of 21 radioactive isotopes. He and Enzo Ricci (formerly of ORNL) were the recipients of the 1977 Radiation Industry Award of the American Nuclear Society for their work on activation analysis. Here, Hahn (center) enjoys life at the end of the periodic table with colleagues from the University of Tennessee—Professor Joe Peterson (left) and Associate Dean Paul Huray.



*So geographers in Afric maps,  
With savage pictures  
fill their gaps,*

*And o'er unhabitable downs*

*Place elephants  
for want of towns.*

*Jonathan Swift  
"On Poetry, a Rhapsody" (1733)*

## Life at the End of the Periodic Table

By RICHARD HAHN

Since the dawn of the nuclear age and the birth of Oak Ridge National Laboratory 40 years ago, many modern-day alchemists have explored the properties of man-made elements. These elements, called "transuranium" because they have atomic

numbers higher than that of uranium, first interested ORNL researchers in 1944 when weighable amounts of plutonium were produced in the Graphite Reactor. Our opportunities in what was already a traditional field of research at ORNL expanded in the mid-1960s with the



construction of the High Flux Isotope Reactor (HFIR), the Transuranium Processing Facility (TRU), and the Transuranium Research Laboratory (TRL).

The transuranium elements are produced in the HFIR by multiple capture of neutrons and separated and purified at TRU for distribution to scientists in the United States and abroad. The TRL is one of the specially selected research centers where studies are performed on the heaviest elements.

The main theme of TRL research with transuranium elements has been the exploration of a region of the periodic table that is relatively new and inaccessible to most scientists. Therefore, our task has been similar to that of the explorers in Africa who sought to fill in the blank spots on the map alluded to by Jonathan Swift in 1733. Our research with the heavy elements has extended our knowledge considerably and tested our ideas concerning how the periodic table is constructed. We have found new isotopes, searched for new elements, and developed ways to prove that a new element has been made. (See Curt Bemis's "Alchemy Updated, or the Genesis of an Element," *ORNL Review*, Summer 1975, which describes ORNL's confirmation of the identity of a short-lived isotope of element 104.)

We have prepared new compounds, made the metals of the elements through einsteinium (element 99), and determined for the first time the various fundamental properties that scientists usually take for granted, such as melting point, color, density, and structure. We have investigated the unique chemical characteristics of these elements that depend upon the properties of the 5f electrons. Also, we have become interested in basic chemical questions that relate to the practical subjects of nuclear reprocessing and waste storage. In this article, I will introduce you to a few of the many different research areas with which we in the TRL are involved. I will start with our research relative to the heaviest elements imaginable and then turn to our research relating to elements at the other end of the periodic table.

### Search for Superheavy Elements

The postulated existence of the so-called superheavy elements—the relatively stable elements that are believed to occur in a region of the periodic table far beyond those that are now known—has greatly interested many scientists. If such elements were indeed discovered, they would be extremely important because they would provide a testing ground for our ideas about how atoms and nuclei are constructed.

Concerning the heaviest known elements, scientists continue to make claims and counterclaims for the honor of having discovered elements 104, 105, and 106. Nevertheless, scientists at Berkeley, Oak Ridge, and Dubna in the Soviet Union have made enough isotopes

of these elements to dispel any doubts about the isotopes' existence. Moreover, accelerator experiments at Darmstadt, West Germany, led to the recent announcements of the discovery of elements 107 and 109.

In all of these cases, however, the isotopes produced have short half-lives, of the order of seconds or less, and low yields; thus, little or nothing is known about the isotopes beyond their nuclear properties. For example, the claim for element 109, made in August 1982, was based on observation of a single atom (made by the fusion of nuclei of iron and bismuth) that lasted less than five-thousandths of a second. It would be extremely exciting if elements with atomic numbers between 114 and 126 could be produced in reasonable yields and with "long" half-lives (minutes or greater) because an entirely new region of the periodic table would be opened up and scientists could then carry out chemical, physical, and possibly even biological investigations of these new elements.

The postulated existence of superheavy elements raises two questions. The first is, Can they exist—that is, will the superheavy elements be stable long enough to be detected? According to theory, the hypothetical superheavy elements lie in an "island of stability" because they have "magic" numbers of protons and neutrons that make nuclei extremely stable. Scientists concerned with the nuclear structure of these elements and their decay modes have made many calculations, which predict that superheavy elements could have half-lives as long as the age of the universe (10–20 billion years). Unfortunately, the uncertainties in these half-life estimates are as large as the half-life values themselves.

The second question is, If these elements can exist, what is the best way to synthesize them? While the two questions are undoubtedly closely related, they are different. As one colleague said to me years ago, "Wouldn't it be tragic if superheavy elements were stable but we could find no suitable route to get to them?"

Several well-publicized claims have been made for the discovery of superheavy elements, either those occurring naturally on earth or in meteorites, or being produced in accelerators. In many cases, the claims were later retracted or refuted. In fact, not one claim has been substantiated.

### An Adventure in Germany

Not dismayed by these failures, about three years ago I became involved with four other U.S. scientists—Ken Hulet and Ron Loughheed of Lawrence Livermore National Laboratory (LLNL), Mike Nitschke of Lawrence Berkeley Laboratory (LBL), and Bob Ferguson of ORNL—in a collaboration with a large group of German scientists from the Darmstadt



*Jim Oliver works with ion-exchange equipment in a glove box to purify einsteinium, while Dave O'Kelley and Joe Halperin (right) confer about the progress of the separation. The material will be used for precise measurements of neutron cross sections of the einsteinium isotope.*



laboratory for heavy-ion accelerator studies, Gesellschaft für Schwerionen Forschungen (GSI), and the University of Mainz. Our aim was to combine the unique capabilities that existed in the United States and West Germany at that time (1979-1980) to produce superheavy elements. The Universal Linear Accelerator (UNILAC) at GSI was the world's only accelerator capable of producing energetic beams of uranium ions, and the HFIR-TRU production program was the free world's only source of very heavy isotopes that could serve as targets for these beams.

Our experiments were based on the results obtained by our German colleagues in bombardments of uranium targets with uranium beams. The researchers found no superheavy elements but observed the production of elements as heavy as element 100 (fermium) that seemed to be correlated with the yields of lighter elements, such as polonium (atomic number 84). Because the coming together of a uranium projectile with a uranium target nucleus should give a total atomic number of 184 ( $2 \times 92$ ), the scientists reasoned that the two uraniums had partially combined and then broken down into two massive partners with atomic numbers 100 and 84.

This conclusion was important because it suggested that the reactants broke down into two heavy elements, not into a multitude of light elements. Thus, it seemed possible that if element 100 could be produced in such a way, so could even heavier elements. We reasoned that our using curium (element 96) instead of uranium would greatly increase our chances of success because (1) it was closer to the superheavy region and (2) its larger number of neutrons—152 vs 146 for uranium-238—should impart additional stability to the products. Therefore, with several LLNL-produced targets of curium-248 from HFIR-TRU and with much equipment for the bombardments, we set off for Darmstadt.

Unfortunately, we did not discover any superheavy elements in these experiments at GSI. Thus, we came home not world famous but much wiser. We had learned to be sensitive to the many pitfalls involved in such a search. As a distinguished chemist friend once advised me, "Beware! The road to the discovery of a new element is littered with the bones of many chemists and physicists."

We also learned several new facts about the nuclear reactions induced by uranium beams. The yields of heavy nuclides up to fermium were about a thousand times larger for the curium target than they were for uranium. Mendelevium (element 101) was produced in

our experiment but not in the ones that had used uranium targets, and we even saw a "hint" of nobelium (element 102). Our use of the heavier target had indeed helped us to get closer to the superheavy region, but, unfortunately, not close enough.

### **A New Try at ORNL**

Another approach to synthesizing a superheavy element, different from the use of a uranium beam, involves the complete merger, or fusion, of a projectile with a target (e.g., calcium plus curium, or more precisely,  $^{48}\text{Ca} + ^{248}\text{Cm}$ ) to produce the excited nucleus of a hypothetical superheavy element (in this example, element 116 with mass 296). Many such combinations of beam and target have been tried in several laboratories, but with no positive results for superheavy element formation. Yet, hope persists for producing such elements because two options still appear open. The first is based on evidence that most previous attempts yielded products that decomposed prematurely because they possessed too much internal energy. It now appears possible to repeat some of the earlier combinations to make products that are much "colder," or less excited, with presumably greater chances of survival.

The second option is based on the fact that very few fusion experiments have been done with einsteinium, the heaviest target element that exists in weighable amounts, because the most abundant isotope, einsteinium-253, has a short half-life of 20 days, whereas einsteinium-254, which has a much longer



half-life of 276 days, is currently available in amounts that rarely exceed 2 micrograms. Many new experiments could be tried if a way could be found to produce greater quantities of the heavier, longer-lived einsteinium isotope.

Toward this end, Joe Halperin, Dave O'Kelley, and Jim Oliver of TRL are currently working with John Bigelow and others at TRU to determine the production cross sections in the HFIR of einsteinium-254 for thermal neutrons and more energetic neutrons. These numbers, which are now poorly known, must be measured accurately because a proposal for a special effort to produce about 40 micrograms of einsteinium-254 is being considered. Based on some old cross-sectional values, this plan sounds promising. Trustworthy values are needed, however, before the time and expense of such a special production run can be justified. We expect to have the answer in a matter of months. Then we will know if einsteinium-254 can be the start of a new route to the island of superheavy elements.

### Chemistry with a Few Atoms

One of the most interesting characteristics of transuranium elements is that they are part of a series of elements that begins with actinium (element 89). In this actinide series, the inner 5f electron shell is progressively filled after the outer 7s shell has been filled and the 6d shell has begun to fill. In this respect, these elements are similar to those of the rare-earth or lanthanide series, in which the inner 4f shell is filled. The 5f actinide series contains 14 elements, ending at lawrencium (element 103). To understand these elements, we must know how their chemical properties depend upon the 5f shell electrons.

In probing an element's properties, chemists often want to know its stable valence or oxidation states. In the rare-earth elements, the predominant ionic state in solution is 3+. That is, these elements have three electrons that can participate in forming chemical bonds with other atoms. For the actinides, the chemical situation is more involved, with elements such as uranium, neptunium, and plutonium having several stable oxidation states, while for the transplutonium elements from americium through einsteinium (elements 95 through 99), the 3+ state is again most stable in solution.

To investigate this question for even heavier elements requires a great deal of effort and ingenuity from scientists because the elements from mendelevium (element 101) on up are not available on a routine basis because they are not made in the HFIR. Fermium (element 100) is the heaviest element produced in the HFIR, and it is produced in only very small amounts. The production chain ends at the isotope fermium-258,

which has an extremely short half-life and decays by spontaneous fission, thus yielding products with much lower masses instead of another actinide element.

The only way to produce elements heavier than fermium is to bombard targets with charged particle beams. Many of these so-called transfermium isotopes have low yields and short half-lives from about an hour to seconds or less. Consequently, if we want to study the transfermium elements, we cannot telephone a supplier (as we often do for the TRU) and say, "Please send me a sample of element 102." We have to produce the element ourselves in an accelerator, such as the Oak Ridge Isochronous Cyclotron; use it rapidly in our chemistry experiment; and when it has completely decayed, make more atoms of the element in another irradiation.

Often the number of atoms made of the desired element is small, ranging from about 100,000 down to only several in any one bombardment (by comparison, a gram atomic weight of an element contains  $6 \times 10^{23}$  atoms). The validity of the results obtained with such small numbers of atoms depends on each atom's undergoing a large number of interactions. This kind of research has been given the name "one-atom-at-a-time chemistry."

If our ideas are correct about how the 5f electron shell is filled, we would expect elements 102 and 103 to have 2 and 3 electrons, respectively, outside the completely filled f shell (which contains a maximum of 14 electrons, written as  $5f^{14}$ ). Because this filled shell is presumably stable, we would expect to find that, upon dissolution, lawrencium loses its outer three valence electrons to become a 3+ ion, while nobelium loses its two electrons to become a 2+ ion.

To test this prediction for nobelium, several years ago Bob Silva, Jack McDowell, Lew Keller, and Jim Tarrant used the isotope nobelium-255, which has a 223-second half-life, to characterize the chemical behavior of nobelium by comparing it with several other known elements. The researchers found that nobelium behaves like the alkaline earth elements, such as barium and calcium. Its most stable oxidation state in solution is clearly 2+; thus, the expectation about nobelium's electronic structure was confirmed.

Nikolai Mikheev of the Soviet Union has argued that the closed  $5f^{14}$  configuration should also exist in element 101 (mendelevium). This suggests that mendelevium would have only one instead of two electrons in its outermost shell. He has presented data that purport to show the existence of the mendelevium +1 ion. If true, this result would be especially significant because no other monovalent ion in either the actinide or lanthanide series is known.

To investigate this possibility, Dave O'Kelley, Jim Tarrant, Dave Hobart (then a University of Tennessee graduate student and now a postdoctoral fellow), and I



Applying pressure on americium metal compresses it and also changes its crystal structure. The appearance of the  $\alpha$ -U structure signifies that partial 5f bonding has occurred as a result of the applied pressure. Normally, 5f electrons in transplutonium elements do not participate in bonding. (This figure was supplied by Dick Haire based on results that he and colleagues at Los Alamos National Laboratory reported in the March 21, 1980, issue of Science magazine. In the drawing, dhcp refers to double hexagonal close packed structure; fcc stands for face center cubic structure, and  $\alpha$ -U means a distorted orthorhombic structure.)

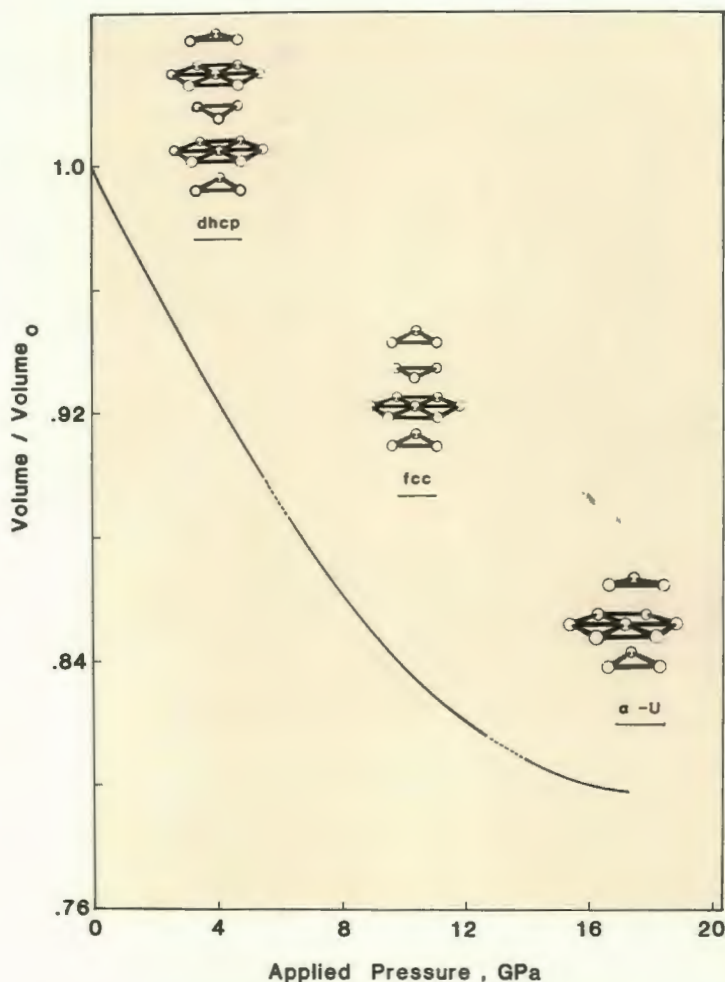
collaborated in late 1978 with two visiting chemists from France, François David and Kamal Samhoun of the Institut de Physique Nucléaire in Orsay. We prepared the isotope, mendelevium-256, which has a 77-min half-life, by alpha particle bombardment of a target that contained only about  $10^{-7}$  grams of einsteinium-254. Our yield was about 20,000 mendelevium atoms per 1-hour irradiation.

In our experiments, we studied the electrochemical behavior of mendelevium relative to fermium, which was also produced in the irradiation. The study showed that the mendelevium and fermium isotopes both behaved as 2+ ions. No evidence was found that mendelevium behaves like a monovalent ion in aqueous solution. Other experiments done at LLNL and LBL also failed to confirm the existence of mendelevium 1+. Thus, no evidence for the existence of this ion has been found by anyone but Mikheev and his coworkers; his prediction of a closed f shell in mendelevium has yet to be proven.

### Localization of 5f Electrons

As our research has progressed, we have asked increasingly complicated questions about the properties of 5f electrons. One question that we have focused on in the past few years is, If the f shell is only partially filled, can these electrons themselves ever participate in chemical bonding? To pursue the answer to this intriguing question, it is necessary to work with weighable amounts of the transuranium elements, especially those from americium through einsteinium.

Pure samples of the metals and compounds are essential. The metals are especially interesting because they represent the elemental states of the actinides. These metals, however, are often more difficult to prepare than are many compounds, because the metals rapidly react with oxygen, nitrogen, and water vapor in the air. Dick Haire has developed the unique capability at the TRL of producing relatively "large" amounts (several milligrams) of transuranium metals and compounds. In fact, the largest amounts of curium-248,



berkelium-249, californium-249, and einsteinium-253 metals ever prepared have been made by Haire at the TRL.

According to present-day wisdom about 5f electrons in the lighter actinides (from actinium to plutonium), the energies of the 5f and 6d shells are similar; also, the 5f orbitals are large and can overlap with other orbitals. Mixing (hybridization) can occur so that the 5f electrons can behave like the 6d electrons and participate in chemical bonding with other atoms. In today's parlance, these bonding 5f electrons are "itinerant" or "delocalized."

In the heavier actinides (americium and above), the increased nuclear charge causes the 5f electrons to be bound more tightly in their orbitals and to have less ability for chemical bonding; these electrons are said to be "localized." To investigate these effects in detail, in recent years Haire has become involved in several collaborative projects, which are sophisticated and require state-of-the-art techniques. The results obtained have given us new insights into "5f electron chemistry."

In one collaboration on magnetic properties, Paul Huray and Stanley Nave of the University of Tennessee





*Dick Haire uses high-vacuum equipment in a helium atmosphere glove box to prepare 8 micrograms of berkelium metal. Berkelium was used in a collaborative research project with Los Alamos National Laboratory to measure the metal's enthalpy of sublimation. Inset: These pieces of berkelium metal on a 6-mm diam quartz disk were cut from a 8-microgram product prepared by reducing a berkelium-fluorine compound ( $BkF_3$ ) with lithium metal.*

Physics Department and Haire have studied the metals and several solid ionic compounds from americium to einsteinium. Working at the extremely low temperatures of liquid helium, they have used a superconducting device at the TRL that can detect the extremely small magnetic flux that is generated when a microgram-sized sample is placed in a magnetic field.

One quantity that Huray, Nave, and Haire have derived from their experiments is the magnetic moment, which reflects the strength of the magnetic field that is produced in the atom by its circulating electrons. Electrons in filled shells do not contribute to the moment; in the actinides, electrons in the unfilled  $5f$  shell make the major contribution to the magnetic moment.

By studying magnetic moments and their temperature dependence in the transuranium elements, we can determine the number of  $5f$  electrons in the actinide species and whether the atoms act as isolated magnets in the solid. As one example, berkelium metal was found to behave as if the atoms were isolated magnets. The measured moment is very close to the value predicted by theory for a berkelium  $3+$  ion in the metallic state. Thus, our ideas about  $f$  electron localization in the higher actinides are borne out by experiment.

Americium is another element with localized  $f$  electrons. Yet its  $5f$  electron properties can be altered by the experimenter. In a recent collaboration by Haire with several scientists at Los Alamos National

Laboratory (LANL), americium metal was subjected to increasingly larger pressures, resulting in profound changes in crystal structure. The method is rather elaborate; it involves compressing small radioactive samples to extremely high pressures and accurately determining structural changes by x-ray diffraction. The results show that as the pressure on americium metal is increased, its structure progressively changes until at about 15,000 atmospheres (15 gigapascals), a significant alteration occurs. At this pressure, americium assumes the structure of uranium metal, in which the  $5f$  and  $6d$  electrons are known to be hybridized. By "squeezing" the  $5f$  and  $6d$  orbitals very hard, the experimenters apparently can force them to overlap enough so that the  $f$  electrons can participate in bonding, that is, become delocalized just like the  $6d$  electrons.

A few years ago, Haire and his colleagues at LANL also discovered that americium metal becomes superconducting at very low temperatures. (Superconductivity is the complete absence of electrical resistivity in some metals.) Elemental americium thus has several intriguing properties, which clearly are related to the question of delocalization of electrons. Research of this type has great significance because it attempts to resolve subtle questions about electronic interactions—questions that can be answered only by experimental investigations of the actinides.

### Radioactivity's Effects on Chemistry

Another aspect of research with the transuranium elements concerns their radioactivity. It is well known that radioactive decay causes chemical change. One reason for this effect is obvious; namely, in most decays, the identity of the element is changed. Another, more subtle reason for such chemical change is that the particle emitted during the decay imparts a recoil "kick" to the atom, thus usually giving the atom enough energy to break chemical bonds and displace other atoms. Studies of "hot atom" chemical reactions and radiation damage explore these phenomena.

The transuranium elements present a unique and convenient opportunity to study the chemical effects of decay. For example, as indicated earlier, a microgram-sized sample of einsteinium-253 will decay, in a matter



*Charles Madic, guest scientist from France, uses a computer to analyze Raman data obtained from cation-cation complexes of the actinides. These unique complexes have important implications for understanding the solution chemistry of these elements.*

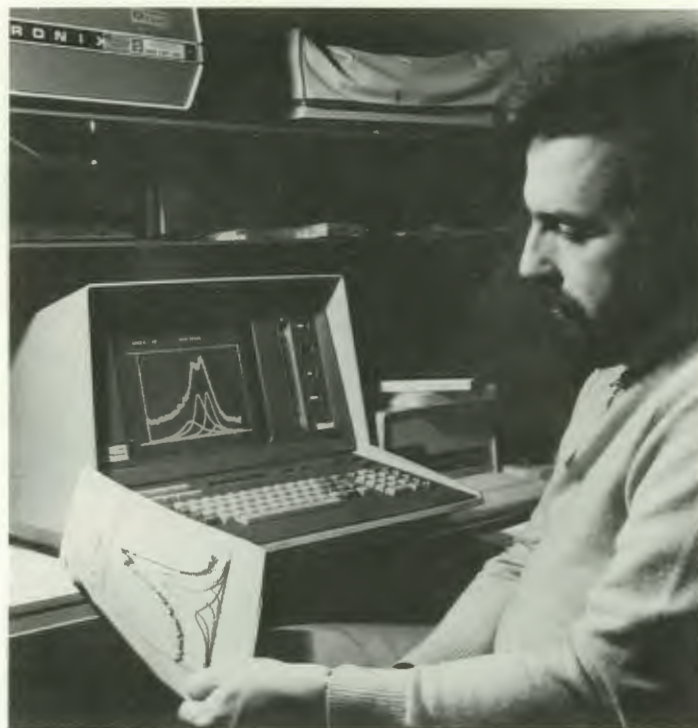
of several weeks, to berkelium-249. Jack Young of the Analytical Chemistry Division; Dick Haire; Joe Peterson of the U.T. Chemistry Department; and Dale Ensor of Tennessee Technological University have tried to determine the fate of the berkelium-249 produced when einsteinium-253 in a particular chemical and crystalline form decays.

The advantages of working with these elements are several. First, it is the only region of the periodic table in which the effects of decay by alpha particle emission can be studied. Second, the half-lives of several of the available isotopes are short enough (but not too short) for the experiments. That is, we have ample time to prepare a compound for study, but we must wait only a few weeks or months for enough atoms to decay to make the effect apparent. And most importantly, the amounts of radioactive elements are "substantial"—micrograms or greater. We can therefore use established analytical techniques, such as spectrophotometry and x-ray diffraction, to determine the oxidation states and structures of the actinide series without disturbing or destroying the sample. Very often, in studies of decay phenomena done with radioactive tracers, it has been necessary to dissolve the solid samples to determine the chemical states involved; the possibility always exists that this dissolution step may cause unwanted changes in the system.

What has been learned so far in research in the TRL is that the chemical state of the daughter, at least in the decay of einsteinium to berkelium, is the same as that of the parent and that the daughter compound conforms to the existing structural form of the solid in which it is formed. Of interest to scientists doing future studies is the chemical fate of a daughter atom whose stable chemical forms are different from those of its parent. What will happen? Will the daughter be able to maintain its own preferred chemical state, or will it be forced to adopt that of its parent? Furthermore, will it be able to accommodate itself to the existing solid phase? The answers to such questions have both intrinsic chemical value and relevance to the long-term storage of nuclear wastes in glasses or crystalline matrices.

### **The Lighter Actinides**

Up to this point, I have discussed mainly the upper end of the transuranium element series. What about the



lighter elements in the series? Because of the importance of uranium, neptunium, and plutonium to nuclear energy applications, much more is known about their chemistry than about that of subsequent heavier elements. Yet even for these lighter elements, we find that there are gaps in our knowledge and even occasional surprises.

For example, for the past three years, we have been collaborating with chemists from the Centre d'Etudes Nucléaires in Fontenay-aux-Roses, France, on studies of unusual species in solution that are known as "cation-cation" complexes. (A cation is a positively charged ion, and a complex is a union of two charged species.) These species, which have been known for about 20 years, are formed by pentavalent actinyl ions with the formula  $AnO_2^+$ , where An stands for the actinide. These species are unusual because the complexes apparently form between the cations; the anions (negatively charged ions) in the solution are chosen because they lack the ability to form complexes with cations. A debate continues in the literature about exactly how these complexes are joined together; some scientists even doubt their existence, although those of us who have worked with the complexes are convinced that they are real.

George Begun, Dave Hobart, and I, in collaboration with French scientists Bernard Guillaume and Charles Madic, have, for the first time, applied a variety of techniques such as laser Raman spectroscopy and x-ray scattering (in collaboration with Al Narten of the





Stan Nave adjusts the micromagnetic susceptometer located at the Transuranium Research Laboratory. This highly sensitive instrument, which incorporates a superconducting quantum interference device (SQUID), is used to derive the magnetic behavior of transplutonium elements in samples as small as 1 microgram.

Chemistry Division) to the characterization of these cation-cation complexes. Consequently, we have learned many new things about these species.

For example, we have shown that neptunium can form a previously unknown dimer, a species in which two  $\text{NpO}_2^+$  ions are joined together, in strong perchloric acid solutions. Besides the fundamental scientific interest in these unusual species, these studies also offer some possible practical aspects. Our data, for instance, suggest that cation-cation complexes may be unexpectedly formed at certain points in nuclear reprocessing schemes and thus may affect the outcome of the separation procedures.

A striking example of how we can learn new and unexpected facts about "known" elements is given by work that Madic, Begun, and I have done with vanadium, which, of course, is not a heavy element. Our interest in vanadium stems from the fact that vanadyl ions,  $\text{VO}_2^+$ , are similar to actinyl ions ( $\text{AnO}_2^+$ ). We have shown that, like the neptunyl ion, the vanadyl ion can form a new species, a dimer. Because we could not believe that it was possible to find a new species of such a well-studied element as vanadium, we carefully searched the literature. Thus, we found that the dimer was indeed new, although several early descriptions refer to "peculiar" behavior that was unexplained prior to our work. The earliest such allusion was written in 1831 by Jons Jakob Berzelius, the renowned Swedish chemist. Therefore, I have suggested to my colleagues that we include him as a coauthor on our paper!

## Chemistry of Waste Disposal

Research at the TRL has also involved practical matters such as the long-term storage of nuclear waste. In one aspect of this work, Carlos Bamberger, George Begun, and Dick Haire have synthesized and studied a variety of actinide-containing solid compounds. Some of these compounds have been made for the first time and are worth investigating because their properties, including possible changes caused by radioactive decay and radiation damage, are not known. The main motivation for these studies is that some of these new compounds might be suitable hosts for storing nuclear wastes.

Another aspect of this research concerns the important question: What chemical reactions might occur if some actinide-containing waste in a geologic repository were exposed to ground water? The information needed for the answer is lacking because until recently most studies of the lower actinides had been done in fairly concentrated aqueous solution in either strongly acidic or basic media. Such conditions are relevant to the nuclear fuel cycle but not to the near-neutral pH conditions and very low concentrations that would be encountered in the environment.

Within the last few years, a program has developed at TRL to characterize the chemistry of uranium to americium under these environmental conditions. Involved in these studies are Joe Halperin, Leon Maya, Bob Meyer, Dave O'Kelley, and Jim Oliver. Of special interest to them are the effects of hydrolysis (chemical reactions of the ions with water) and of complexing agents such as carbonate that are prevalent in the environment. For example, while carefully characterizing the hydroxyl and carbonate species of the uranyl ion,  $\text{UO}_2^{2+}$ , Maya recently found a previously unknown species containing both  $\text{OH}^-$  and  $\text{CO}_3^{2-}$  groups. Halperin has studied the complexation of neptunyl ions by sulfate and bisulfate ions. Similar investigations are being performed on plutonium and americium.

The complete characterization of such species is vitally needed as input for theoretical predictions of the long-term migration of radioactive elements through the geosphere. Because the times involved are much longer than human lifetimes, recourse to calculations is necessary. The more complete and reliable the data base is, the more trustworthy will be the projections that are



## A Look at Transuranium Elements

The first attempt to produce a transuranium element was made in the mid-1930s when Italian physicist Enrico Fermi tried unsuccessfully to synthesize an element heavier than uranium by irradiating uranium with neutrons. However, although many new radioactive products were observed in his experiments, Fermi's attempt to build a new element actually resulted in the splitting of the target element. In an attempt to understand Fermi's confusing results, Germany's Otto Hahn and Fritz Strassmann conducted crucial chemical experiments in 1938 that proved the existence of a new phenomenon, nuclear fission.

American experimenters, including Nobelist Glenn Seaborg, then succeeded in synthesizing elements with atomic numbers larger than that of uranium (92). From 1940 through 1961, elements 93 through 103 were identified. Their names are neptunium (Np), plutonium (Pu), americium (Am), curium (Cm), berkelium (Bk), californium (Cf), einsteinium (Es), fermium (Fm), mendelevium (Md), nobelium (No), and lawrencium (Lr).

Some of these elements are more familiar than others. Perhaps the best known is plutonium, gram quantities of which were produced in ORNL's Graphite Reactor during the mid-1940s. Plutonium is an ingredient of nuclear weapons and an important fuel that can be bred in light-water reactors and breeders such as the Clinch River Breeder Reactor. Americium is used in home smoke detectors. Curium is an element for the space age—it has provided power for satellites and rockets. Californium is an important source of neutrons used widely for studying activation analysis, starting nuclear reactors, and treating cancerous tumors.

Man-made transuranium elements have several unique characteristics that make them especially worthy of study. Although these elements occupy the very end of the periodic table, they comprise about 20% of the known elements. They serve as the jumping-off places in attempts to synthesize even heavier elements. They are part of the actinide series of elements, in which it appears that the 5f inner electron shell is being filled with no addition of electrons to the outermost shells. Also, they are radioactive, decaying mainly by emission of alpha particles (helium nuclei) or by spontaneous fission.

While accelerators have been used as the chief tool for discovering new elements, nuclear reactors generally are employed to produce these elements in weighable

amounts because reactors produce high intensities of neutrons and can irradiate large samples over a long time. In a reactor, the target nucleus that captures neutrons becomes so neutron-rich or "topheavy" that one or more of its neutrons may decay into protons, thus forming an element with an atomic number higher than that of uranium.

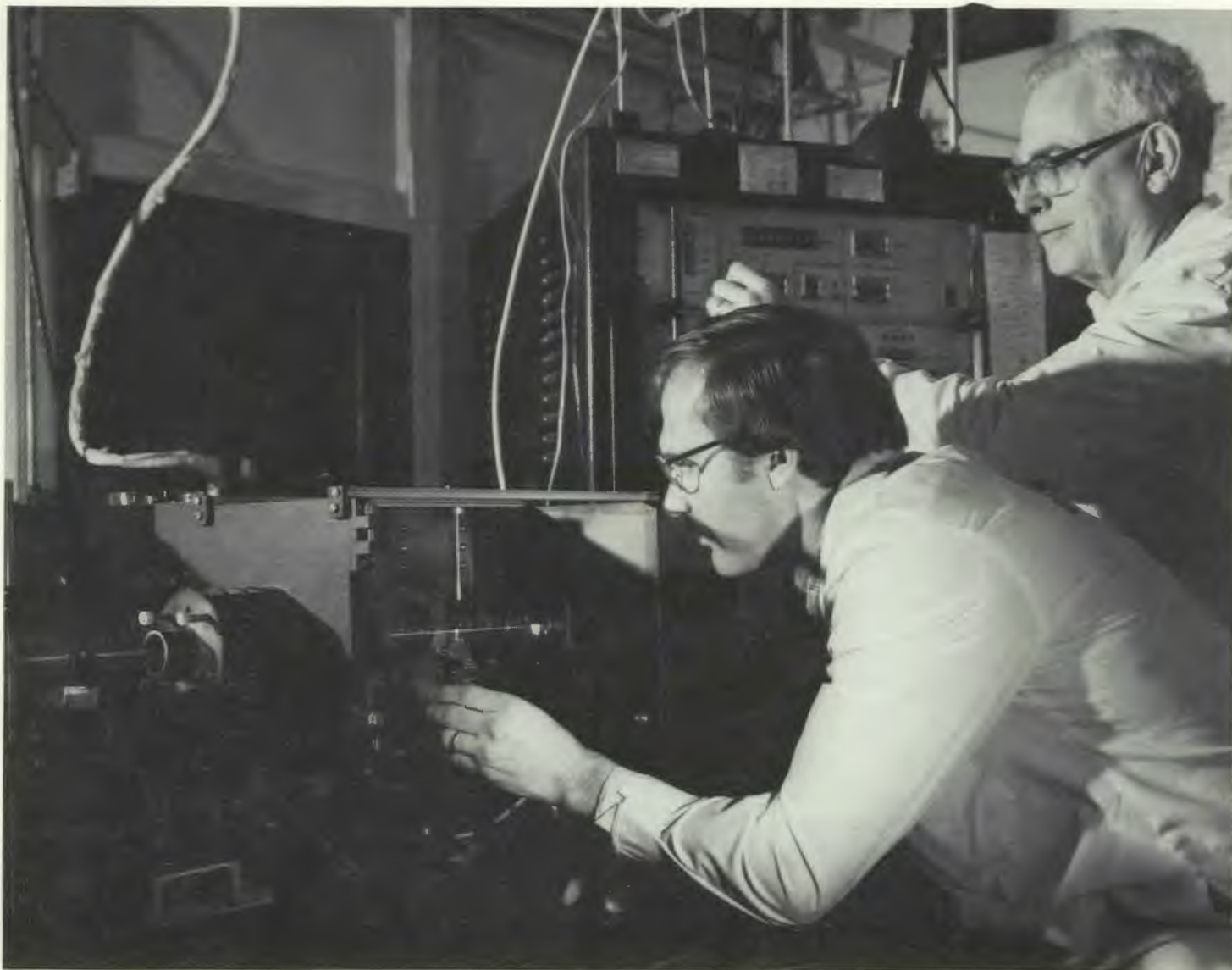
Recognizing the need to synthesize weighable amounts of transuranium elements, the Atomic Energy Commission started a national program to produce these elements in Oak Ridge in the mid-1960s. At that time the High Flux Isotope Reactor, Transuranium Processing Laboratory, and Transuranium Research Laboratory were built.

Although TRL researchers have access to reactor-produced transuranium elements, they do not necessarily have a lot of material to work with. Some isotopes such as curium-248, berkelium-249, and californium-249 are available only in milligram amounts, while the total annual production of einsteinium-253 amounts to no more than 1 milligram and the amount of fermium-257 is merely 1 picogram ( $10^{-12}$  gram). Because of these small amounts of material, specialized microscale techniques had to be developed for working with these elements.

TRL researchers have to cope with other constraints, too. Because transuranium elements are radioactive, TRL scientists must follow stringent safety procedures and work with these materials in glove boxes in special laboratories that provide reliable containment. The radioactive nature of these elements can cause other problems for the scientist; for example, radiation damage and self-heating can produce unwanted or unexpected effects in samples. As an extreme example, einsteinium-253, because of its 20-day half-life, literally disappears before the experimenter's eyes. A researcher starting with a pure sample of einsteinium-253 will find that even one day later the sample contains an appreciable "impurity" because each day about 3% of the einsteinium decays to berkelium-249.

Despite such constraints, TRL researchers are dedicated to their goal of finding out more about the elusive man-made elements that can shed light on the workings of nature. It is a formidable task, as Fermi discovered when he tried his hand at it nearly 50 years ago.





made as to how these elements will behave in repositories.

*Dave Hobart (front) and George Begun adjust the laser to examine the Raman spectra of a sample of americium orthophosphate.*

### Epilogue

The newness and rarity of many of the transuranium elements add a unique flavor to much of our work. It can be an exhilarating experience to be one of only a handful of scientists, or perhaps even the first one, to prepare a new compound or to observe some new phenomenon associated with these elements.

Because of the special equipment required in this field, the TRL is a very special facility, one of a limited number of laboratories in the world where such research can be performed. Thus, the TRL has attracted numerous scientists from universities, other national laboratories, and several foreign laboratories (as, those, for example, from our "French connections") who have made important contributions to our research.

The more we have learned about these elements, the more refined and sophisticated have been the questions that we have been able to ask in our experiments. State-of-the-art techniques, such as Raman spectroscopy, high-temperature mass spectrometry, and neutron scattering, are new additions to our arsenal of methods, and these techniques are helping us to obtain detailed answers about the actinide species that exist in the gaseous state and in concentrated solutions. Much remains to be done with the transuranium elements. They inhabit a part of the periodic table that is still considered far away and exotic by most scientists. However, we believe that it is worth the effort to try to conquer this region so that we can understand the structure and properties of matter at the end of the periodic table of the elements. [ornl](#)





## BOOKS

### ***Advances in Energy Systems and Technology*, ed.**

*Peter Auer, Academic Press, New York (1982), 290 pp. Reviewed by William Fulkerson, Director, ORNL Energy Division.*

I was pleased to review this volume because ORNL Energy Division researchers, Garland Samuels, Axel Rose, David Greene, and John Hooker, wrote the 100-page chapter "Energy Conservation in Transportation." The other two chapters—"Unconventional Natural Gas" by V. Kuuskraa and "The French Nuclear Program" by E. Bertel, A. Ferrari, and C. P. Zaleski—concern equally important subjects. These three topics seem more relevant to the present climate of energy policy than do those in the first two volumes of this series, which focus largely on so-called renewable energy sources, with some mention of clean fuels from coal and models for assessing energy technology.

All three chapters contain much useful information as well as some general messages. For example, V. Kuuskraa of Lewin and Associates,

Inc., describes the difficulty of maintaining the present supply of natural gas at about 19 EJ/year through the year 2000. He estimates that conventional sources (including imports) can be expected to supply only 9–15 EJ/year in the year 2000 and that the likely rate of production of gas from unconventional formations will be in the range of 3–6 EJ/year, if gas prices exceed \$4–5/GJ.

Unconventional formations that Kuuskraa thinks may provide that supply are Devonian shales and tight gas sands, but a supply rate of 3–6 EJ/year can be achieved from these sources only through the application of advanced technology. Kuuskraa, who lectured on these sources at ORNL in August 1980, also writes about coal deposits and geopressurized brine as sources of natural gas, but he does not speculate on possible production rates from coal or brine. However, he predicts that tight gas sands will be the major source of unconventional natural gas.

The chapter on the French nuclear program describes the overall French energy strategy as a balanced approach that appears to be largely immune to partisan politics. France's strategy

emphasizes (1) conservation, (2) replacement of oil combustion by nuclear and solar energy, and (3) reduction of vulnerability to cutoffs of oil imports by increasing domestic production and diversifying supply sources. This strategy is implemented by government policies and a close partnership between government and industry.

By 1990, the end of the present French planning period, primary energy use will be increased by only about 10%, and consumption of imported oil will be reduced from the present level of 56% to 28% of primary energy supplies. Most of the reduction in oil use will be accomplished by the substitution of nuclear fuel for oil to generate electricity. Interestingly, the amount of energy saved as a result of conservation investments is estimated to be 60 megatons of oil equivalent per year by 1990—an amount almost equal to the energy that will be supplied by nuclear reactors that year. The conservation capital investment over the 1980–90 period is projected to be 159 billion French francs (BFF) (\$30 billion), roughly comparable to the 150 BFF forecast for the nuclear program for the





*Two of the ORNL authors of the book's chapter on transportation systems are David Greene, left, and Garland Samuels.*

1978-88 period.

In the French scheme, both conservation and nuclear energy are institutionalized by government agencies. The French government spent 716 million French francs (\$136 million) on conservation programs in 1980, which amounts to \$2.50 per capita. By comparison, the U.S. Department of Energy spent about \$1.50 per capita in FY 1981 (excluding tax credits or money spent by other government agencies).

France's dedication to nuclear energy is undoubtedly motivated by economics. Nuclear electricity costs about one-half as much as coal-generated electricity and one-third as much as oil-generated electricity. The cost per kilowatt hour for nuclear electricity is 13.5 centimes (2.6 ¢). Most of France's nuclear electricity comes from pressurized water reactors (PWRs) based on a Westinghouse design but built in a somewhat standardized, mass-produced fashion in France under Westinghouse licensing agreements. The French, however, now plan to construct huge [1.5 GW(e)] liquid-metal-cooled fast breeder reactors that are estimated to ultimately produce electricity at a cost 10% higher than the cost of power


generated by PWRs. The Superphenix, a 1.2-GW(e) plant that is scheduled to begin operation in 1984, is expected to have a capital cost 2.3 times as high as that of a typical PWR.

The ORNL researchers' chapter on "Energy Conservation in Transportation" provides a comprehensive review of the state of the technology devoted to reducing fuel consumption by making more efficient automobiles. The authors also discuss efficiency improvements in trucks, aircraft, ships, and pipelines.

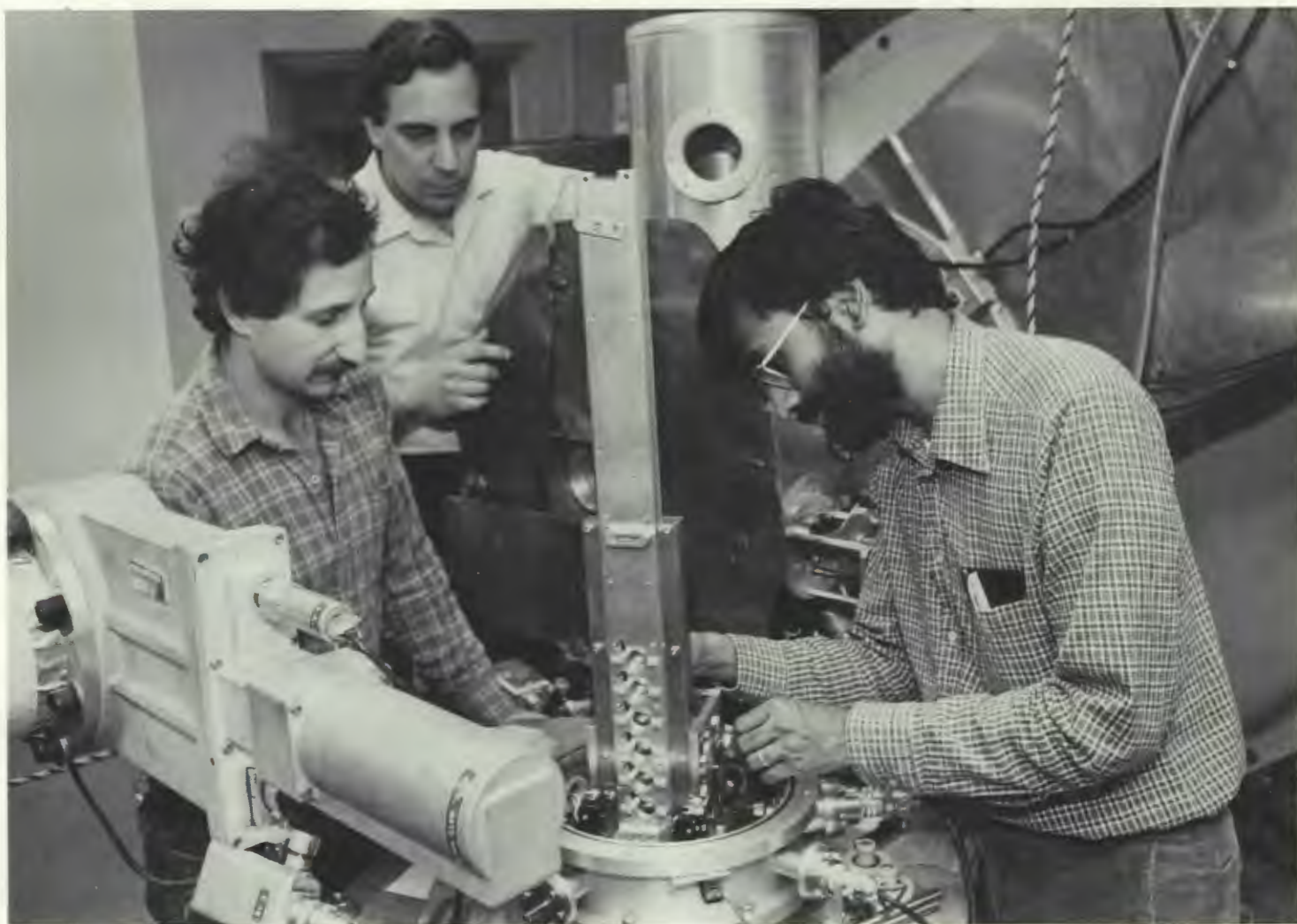
The ORNL researchers conclude that the internal combustion engine, particularly the diesel, will be the most energy-efficient power source for the automobile. Electric and hybrid vehicles, Rankine engines, Stirling engines, and gas turbines all look poor by comparison to internal combustion engines unless some major breakthroughs occur. Because Stirling and gas turbine engines are temperature limited, they require better materials. The Rankine cycle needs a better, higher-temperature working fluid than steam, and the electric and hybrid vehicles have a reduced speed and range because of their limited energy storage devices.

The major problem faced by engineers in redesigning internal combustion engines is the difficulty in achieving high efficiencies without violating emission standards. The problem is most severe for nitrogen oxides. If standards become more stringent, an advanced Stirling engine might overtake the internal combustion engine someday.

Present technology has attained efficiencies of 21 ton-km/L for diesels, and efficiency improvements from 20 to 40% over current designs seem possible. In addition, much can be done to improve vehicle aerodynamics, reduce weight, and improve transmission systems. Combined with engine modifications, these improvements promise a boost in the efficiencies of diesel-powered small cars and small trucks and, to some extent, of large trucks and aircraft.

How quickly these changes will occur depends on the price of fuels and the success of research. However, the potential for continuing across-the-board efficiency improvements in transportation is indisputable. 





# NEUTRON SCATTERING:

By V. R. RAMAKRISHNAN

**T**housands of chemical reactions take place in a living cell. These reactions must be delicately balanced and controlled for the cell to go on living. Furthermore, a living cell contains within itself the information necessary to grow and to reproduce. How these processes occur and how they continue are questions that molecular biologists are trying to answer.

During this century, important advances have been made in better

understanding life at the molecular and chemical level. As a result, it is now well established that the various chemical reactions that make life possible are catalyzed and controlled by special molecules called enzymes. The information required to make these enzymes and to enable the cell or a living organism to grow and multiply is found in genes. Until the last 40 years, the concept of the gene was somewhat nebulous in that nothing was known about its chemical

nature. Now it is known that a gene, which determines the hereditary characteristics of an organism, is chemically a part of a long molecule of deoxyribonucleic acid (DNA). DNA is present in most cells as a complex with certain specific proteins in the form of chromatin.

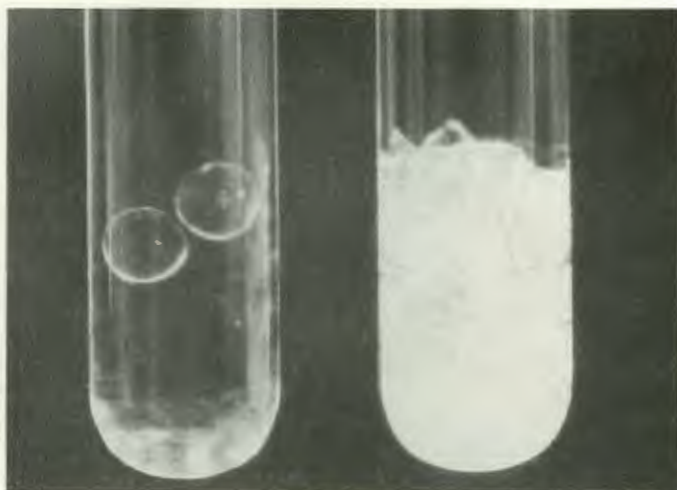
Both enzymes and genes exist in the form of very large molecules, called macromolecules. To understand how these macromolecules function, it is



Venki Ramakrishnan was born in Chidambaram, India, and grew up in Baroda, India, where he received his undergraduate training in physics. He earned his Ph.D. degree in physics from Ohio University in 1976. By that time, however, his interest had shifted to biology; thus, he became a graduate student in biology at the University of California, San Diego, in La Jolla, where he worked on the properties of rhodopsin in planar lipid bilayers. From 1978 to 1982, he was a National Institute of Health postdoctoral fellow at

Yale University, where he worked on the structure of the ribosome. In the spring of 1982, he came to ORNL's National Center for Small Angle Scattering Research (part of the Solid State Division), where he is the center's staff member responsible for biological problems. At the Center he has been collaborating with various groups using small-angle scattering to resolve problems relating to biological structure. His main interest is the structure of proteins and macromolecular aggregates and the relationship of

structure to function and recognition. Here, using the small-angle neutron scattering instrument at the High Flux Isotope Reactor, he prepares to conduct a biological experiment. Here, at the small-angle neutron scattering instrument at the High Flux Isotope Reactor, he prepares the automatic sample changer for use in the sample chamber. Looking on are Gerald Bunick (top) and Ed Uberbacher of the University of Tennessee—Oak Ridge Graduate School of Biomedical Sciences.



*The concept of contrast matching is illustrated in this photograph made by Professor Donald Engelman of Yale University. Both tubes contain two Pyrex beads embedded in glass wool, which has a lower refractive index than the Pyrex. The tube on the left has been filled with a solvent consisting of 95% dimethyl sulfoxide, which has the same refractive index as the glass wool. When light shines on the tubes, only the Pyrex beads are visible in the tube at left because the glass wool has been contrast matched and is thus transparent. In the tube at right, both the beads and glass wool scatter light, but only the glass wool can be seen because it dominates the scattering.*

## A Tool to Probe Biological Structures

important to learn something about their three-dimensional structure because the properties of these large molecules are radically different from the simpler chemical building blocks from which they are assembled.

These macromolecules, while large by the standards of ordinary chemistry, are nevertheless too small to be seen under the light microscope. Several physical techniques, among them electron microscopy and x-ray

crystallography, have been used to determine their structure. Although most of these techniques are useful, each has limitations. Thus, it is often necessary to use a combination of methods to understand the structure of a biologically important molecule.

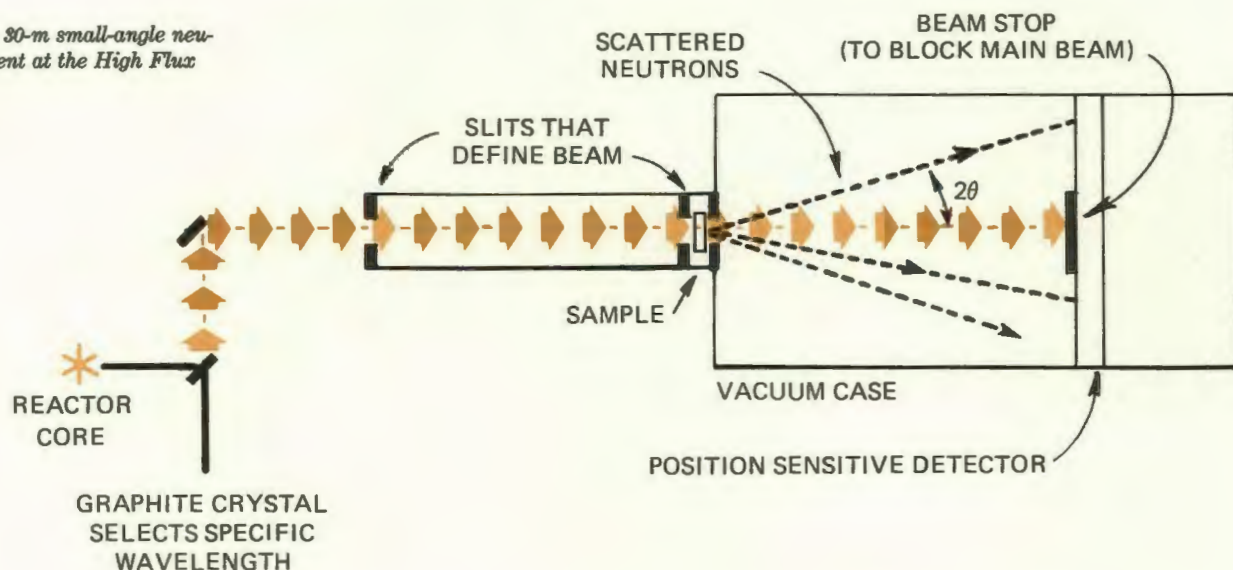
A technique that has been increasingly used in the past few years to study biological structures is small-angle scattering. When a beam of radiation (X rays, or neutrons in this case) strikes a

solution of macromolecules, much of the radiation is scattered in directions close to that of the incident beam—hence, the name “small-angle” scattering. The scattered radiation in this small-angle region provides information about the overall properties of the macromolecule (e.g., its size, shape, molecular weight and volume, and surface area).

In the initial stages of the study of a macromolecule, this kind of information is extremely valuable.



Schematic layout of the 30-m small-angle neutron scattering instrument at the High Flux Isotope Reactor.



Even when the molecule's detailed structure is known, small-angle scattering is useful to determine the kinds of changes that occur as the environment of the macromolecule is changed. These changes provide important clues about how the macromolecule works.

### Scattering Length Density

Although the basic theory of small-angle scattering is almost 50 years old, the range of biological problems that can be examined by this technique has been greatly extended in the last 10 years by the use of small-angle neutron scattering. Neutrons are particularly useful in this context because they are scattered quite differently by the nuclei of hydrogen (H) than they are by its heavier isotope, deuterium (D). This phenomenon is important because the scattering by a particle in solution depends on the difference between the scattering properties of the particle and the solvent; thus, one way scientists can create a difference is to alter the scattering properties of a water-based solvent by substituting D for H.

The difference between the density of the particle and the solvent is called *contrast*. In this case, "density" refers not to mass but to a special kind of density called "scattering length density"—a measure of how strongly a unit volume of a substance scatters incoming radiation. In the case of light scattering (as occurs when a light beam strikes an emulsion of oil droplets in water), the analogous density is the index of refraction, which is the ratio of the speed of light in a vacuum to its speed in a second medium such as oil.

If there were no difference between the scattering length density of the particle and the solvent, no small-angle scattering of neutrons from the particle would occur. This condition is called *contrast matching*. The fact that H and D nuclei scatter neutrons differently means that we can change the contrast of a solution of macromolecules by changing the scattering length density of either the solvent or the macromolecule, producing what is called *contrast variation*.

Changing the solvent's scattering properties is quite easy to do.

Because biological molecules are usually studied as a solution in water, the scattering length density of the water can be changed by replacing ordinary water (H<sub>2</sub>O) with heavy water (D<sub>2</sub>O). By selecting different ratios of H<sub>2</sub>O to D<sub>2</sub>O, we can vary the contrast over a wide range. Replacing ordinary water with heavy water produces no significant chemical changes, but it causes quite drastic differences in the ways that macromolecular particles and the solvent scatter neutrons.

Changing the scattering length density of the macromolecule is much more difficult; it has been done by obtaining deuterated forms of the molecule by growing the organism that produces the macromolecule in a medium containing heavy water. The result is a macromolecule that is similar to its normal counterpart except that most of the hydrogen atoms in it are replaced by deuterium atoms.

### Contrast and Complexes

Contrast variation is useful in the study of complexes of macromolecules of different scattering length densities. For



example, biological membranes consist of lipids and proteins that scatter neutrons differently. The same is true of complexes of nucleic acid and protein, many of which exist in cells. Ribosomes are complexes of ribonucleic acid (RNA) and proteins that are essential in the translation of the genetic code into functional proteins. Chromatin, which is discussed below, is a complex of DNA and proteins.

Many of the processes that determine how the information in genes is used to make corresponding proteins involve the interaction of specific proteins with specific regions of DNA or RNA. These also constitute protein-nucleic acid complexes.

By selecting a correct  $H_2O:D_2O$  ratio in the solvent, we can contrast-match it with one component of a complex and thus obtain information about the other component. A series of contrast variation experiments on a complex then produces information not only about the state of each component but also about the arrangement of components in the complex. This is a far more detailed picture than we can obtain with conventional small-angle scattering experiments.

### A New Instrument

If neutron scattering is so useful and if the basic theory behind it has been known for years, why has it only recently been applied to biology? Traditional neutron sources, which have been used by physicists for decades, are too weak to be of use in most biological experiments, in which the amount of available material is usually limited to a few milligrams. Today, however, we have position-sensitive detectors, many of which were developed in Oak Ridge during the past decade based on a concept originated by Cas Borkowski and Manfred Kopp of ORNL's

Instrumentation and Controls (I&C) Division. These detectors, which make it possible to measure the scattered radiation at all angles simultaneously rather than at just one angle at a time, have speeded up experiments by a factor of more than 100. When used in combination with the more intense neutron sources available from high-flux reactors, position-sensitive detectors have made possible the development of small-angle neutron scattering instruments that are suitable for routine use by biologists.

Six such instruments exist. One of these is the 30-m small-angle instrument designed by William Taylor Clay and built by Charlie Fowler, both of whom are in the I&C Division. This instrument, which is located at ORNL's High Flux Isotope Reactor, is funded by the National Science Foundation as part of the National Center for Small Angle Scattering Research, a user-oriented facility at ORNL.

Since I came to Oak Ridge last spring, I have been collaborating with various groups, mainly from the Biology Division and the University of Tennessee-Oak Ridge Graduate School of Biomedical Sciences, on biological experiments using the small-angle instrument. We have applied techniques developed at other small-angle instruments at Brookhaven National Laboratory and in West Germany and France. Some of these experiments and their results, which are summarized in the following discussion, illustrate the kinds of problems that can be studied by small-angle neutron scattering.

### Chromatin and Genes

DNA, the genetic material of most forms of life, is packaged in the cells of higher organisms in the form of chromatin, which is a complex of DNA with specific

proteins. Some of the pioneering work on the structure of chromatin was performed by Ada and Don Olins of the Biology Division and the University of Tennessee-Oak Ridge Graduate School of Biomedical Sciences. Their work helped to establish that chromatin has a basic subunit, called the nucleosome, which consists of DNA complexed with proteins called histones. An early biological application of neutron scattering was the demonstration by two European groups that the nucleosome consists of a core of eight histones around which the DNA is wound.

How genes are activated is a central question in biology today. Much of the chromatin in a cell is inactive; that is, the genes that reside on the DNA in many regions are not being used to make corresponding proteins. The activation process, therefore, is thought to involve changes in the structure of chromatin.

In an attempt to identify possible changes in chromatin structure, Gerard Bunick and Edward Uberbacher of the University of Tennessee-Oak Ridge Graduate School of Biomedical Sciences in collaboration with Don Olins have looked for structural changes in specific proteins, called HMG-14 and HMG-17, are known to bind to nucleosomes and are thought to play a role in the activation of chromatin. Bunick and Uberbacher tried to determine the effect of these two binding proteins on the structure of the nucleosome. From their small-angle scattering experiment, they concluded that the structure of the protein core of the nucleosome changed very little when the HMG proteins were bound; they did find, however, that the DNA unfolded slightly.

In another experiment, Bunick, Uberbacher, and I studied the effect of lowering the ionic strength of the solution on the structure of



nucleosomes. Various other groups had postulated that there may be a dramatic change of the nucleosome from a compact to a highly elongated shape, which might correspond to an activated state of the nucleosome. We showed that, in fact, the protein core structure of the nucleosome is preserved at low ionic strengths and that the DNA unwinds from the ends but remains partially wrapped around the protein core.

Both of these experiments suggest a mechanism for the unfolding of DNA by which the DNA unwinds from the ends while the compact protein core is left intact. This kind of mechanism may be involved in the changes in the structure of chromatin during the activation of genes. In this context, neutron scattering has been a particularly useful technique because it has been possible to separate precisely the contributions of the protein core and the DNA by contrast variation.

### ATPase

Energy is stored in the cell in the form of adenosine triphosphate (ATP), a molecule that acts as the cell's "energy currency." When ATP is broken down by reaction with water (hydrolysis), the energy is released for use in various reactions. Most of the ATP in the cell is formed in a process where a proton gradient across a membrane is used to provide the energy needed to make ATP. This process is carried out by an enzyme called proton translocating ATPase, which consists of two parts: a part called F<sub>0</sub> that traverses the membrane and is responsible for moving the proton from one side of the membrane to the other, and a part called F<sub>1</sub> that sticks out of the membrane and is responsible for the actual formation of ATP. F<sub>1</sub>, which can be separated in soluble

form from the membrane-bound F<sub>0</sub> part, is a complex of five kinds of proteins, which are called  $\alpha$ ,  $\beta$ ,  $\gamma$ ,  $\delta$ , and  $\epsilon$ . The exact number of copies of each of these proteins in F<sub>1</sub> is a matter of controversy.

In collaboration with Yasuo Kagawa of Jichi University in Japan, I have begun studies on the structure of F<sub>1</sub> ATPase. Even the preliminary experiments on this enzyme have produced interesting results. The molecular weight determined from this study showed that the composition of F<sub>1</sub> is probably  $\alpha_3\beta_3\gamma\delta\epsilon$ . This finding disagrees with many previous results but agrees well with recent biochemical data.

We also showed that no major changes take place when ATP is bound to the enzyme. This, too, was a matter of debate. We were able to confirm the presence of a cavity in F<sub>1</sub>, which had been seen in previous experiments by other groups.

Much more information, however, can be obtained from neutron scattering on the arrangement of the various individual proteins in F<sub>1</sub> by using a clever idea originally developed for the ribosome by Donald Engelman and Peter Moore of Yale University. Their idea is to study a complex of several proteins in which one or two proteins are present in deuterated form.

By studying biologically reconstructed F<sub>1</sub> complexes that have specific proteins that are deuterated under conditions in which the rest of the complex is contrast-matched, we can obtain information about the deuterated regions alone. By repeating experiments in which different proteins of F<sub>1</sub> are deuterated, we should learn about the shape and arrangement of the individual proteins that make up F<sub>1</sub> and arrive at a much more detailed picture than would be possible from a single small-angle scattering experiment.

### Structure of Viruses

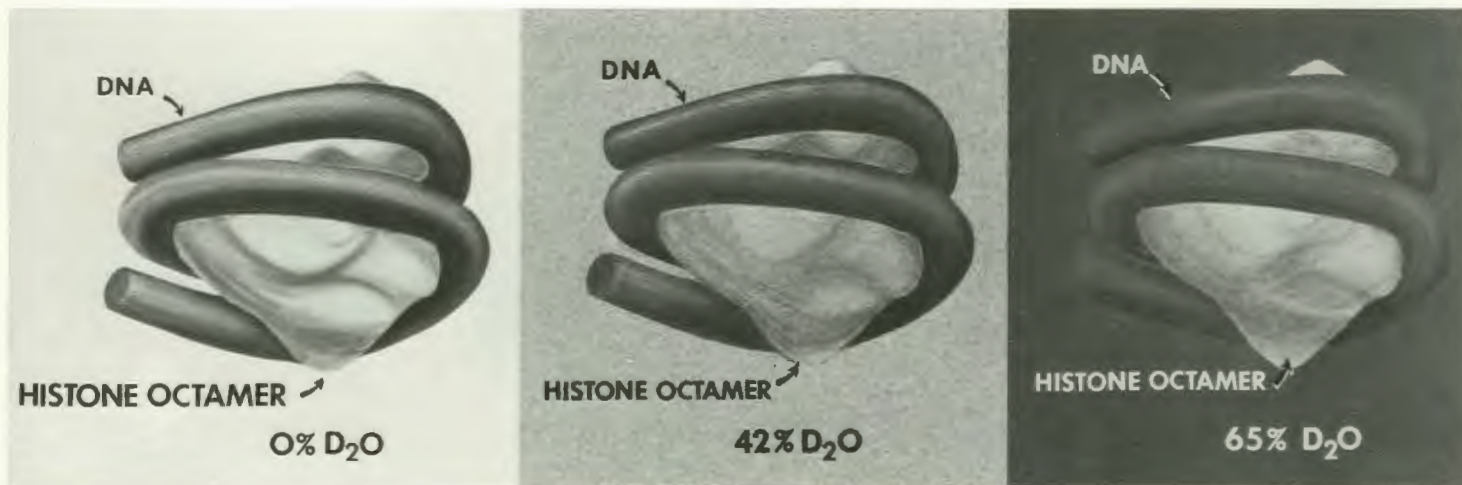
The structure of viruses is yet another area where neutron scattering is useful. Small-angle scattering is particularly useful for studying a class of viruses called spherical viruses. These viruses exist in their mature form as capsids, which consist of RNA or DNA packaged in a shell of protein. Each shell is icosahedral in shape, that is, it is a 20-faced polyhedron that approximately resembles a sphere.

Usually, because biological molecules are asymmetric in solution, they assume random orientation, thus resulting in a loss of much structural information. Therefore, it is not possible to reconstruct unambiguously the molecule from scattering data of molecules in solution. In the case of spherical particles, however, randomly orienting the particle leaves it essentially unchanged so that, in effect, we are looking at particles in solution that have the same orientation. Consequently, we can reconstruct spherical shapes from scattering data on such particles in solution.

By itself, this is not particularly useful information, because we already know that the particles are spheres. By the use of contrast variation, however, we can determine separately the structure of the protein shell and the nucleic acid inside the shell (because proteins and nucleic acids scatter neutrons differently). We can determine also to what extent the protein shell penetrates into the interior of the virus and how the nucleic acid interacts with the protein shell.

Much work of this kind is being done by B. Jacrot of the European Molecular Biology Laboratory in Grenoble, France. Also, Sankar Mitra of ORNL's Biology Division and his co-workers have been





How contrast matching with neutrons can be used to obtain structural information about the nucleosome is shown in these three drawings. At left, a nucleosome is shown in a solvent of ordinary water that is not deuterated (0% D<sub>2</sub>O); at this contrast, both the protein core and the DNA show up in the scattering. In the middle picture of the nucleosome in 42% D<sub>2</sub>O, the protein core is nearly invisible, and the scattering is mainly from the DNA. At right, the DNA wrapped around the nucleosome in a solvent of 65% D<sub>2</sub>O is contrast matched; thus, the scattering comes mainly from the protein. By studying the nucleosome at different contrasts, one can look separately at the structure of the DNA and the protein core.

studying various aspects of a virus called the Kilham Rat Virus (KRV), which is an interesting virus because the DNA in this virus has an unusual structure. The KRV DNA is single stranded—unlike most forms of DNA, which consist of two strands intertwined in the familiar double helix—and has hairpin turns at both ends. Recently, Rick Wobbe of the University of Tennessee–Oak Ridge Graduate School of Biomedical Sciences and Mitra have begun neutron-scattering studies on KRV using Jacrot's techniques. The researchers hope to determine the structure of the viral capsid's protein shell, to determine the structure of the DNA inside the shell, and to characterize changes in the structure of the spherical virus as conditions are changed.

### Structure of Enzymes


Finally, small-angle scattering is quite powerful when used to answer a question calling for a "yes" or "no" answer, such as whether an

overall change in the structure of a macromolecule occurs under various conditions. Consider ribulose biphosphate carboxylase/oxygenase, an enzyme prevalent in all photosynthetic organisms. This life-giving enzyme fixes gaseous carbon dioxide from the atmosphere into organic molecules in green plants and certain bacteria for conversion into sugar. Because humans and animals are unable to fix CO<sub>2</sub>, they must eat food made by plants to survive. Two forms of the enzyme exist: the form in green plants and certain photosynthetic bacteria that consists of eight large and eight small subunits and a smaller form in some other photosynthetic bacteria, such as *Rhodospirillum rubrum*, that consists of only two large subunits.

Following a report that the larger form of the enzyme changes structure dramatically when activated by the binding of carbon dioxide and magnesium, Mark Donnelly of the University of Tennessee–Oak Ridge Graduate School of Biomedical Sciences and

Fred Hartman of ORNL's Biology Division, who have been involved in various biochemical studies to determine how this enzyme works, collaborated with me to investigate this question, Does the smaller form, the *rubrum* enzyme, undergo any structural change upon activation and, if so, what changes occur? To our surprise, we found that activation caused virtually no change in the overall shape of the *rubrum* enzyme. This finding indicates that if the report on the larger form of the enzyme is true, the change must involve an interaction with the small subunits, which are absent in the *rubrum* enzyme.

### Conclusion

No single physical technique is capable of revealing everything about how a biological macromolecule works. Small-angle neutron scattering, when used in combination with biochemical and other biophysical techniques, can often provide information about the structure of complexes of biological molecules and about the nature of the changes in structure that occur during reactions involving these molecules. Such information is extremely useful to further our understanding of the processes that take place in living organisms. 



## Microwave Spectrometry

Sensitive analyses for specific compounds in gases have been achieved by microwave absorption spectrometry. In this technique, microwaves of a characteristic frequency are absorbed by a given molecule, which is excited to a higher rotational energy level. Because a portion of the microwave energy directed into the gas is absorbed, less microwave energy comes out. By measuring the portion of the incident energy that comes out and then calculating how much energy was absorbed, scientists can identify a specific molecular substance and determine how much is present. The microwave frequency at which a particular molecule absorbs depends on molecular structure; thus, the technique is sensitive to chemical additions and isotopic substitution.

Conventional microwave spectrometers are complex, large, expensive, and relatively slow in differentiating among a number of molecular species in the same gas. Now, a novel microwave absorption spectrometer that is expected to overcome these deficiencies is being developed by Mike Ramsey and Bill Whitten of ORNL's Analytical Chemistry Division. The ORNL instrument is expected to be simpler, smaller, and less expensive than conventional instruments and to have an enhanced signal-to-noise ratio. The ORNL device is also potentially faster and more sensitive than are conventional microwave spectrometers and, unlike its conventional counterparts, will be able to identify simultaneously more than one particular molecular species.

Ramsey and Whitten's technique is called Fourier transform microwave spectrometry because of its ability to identify simultaneously several molecules in a gaseous mixture if these different molecules absorb in a frequency range of the broad-band microwave source. The sensitivity of the new instrument is not yet as good as that of mass spectrometry, but the researchers believe that, with developmental improvements, the instrument will eventually be able to detect substances at levels as low as 1 ppm.

"The simplicity and small size of our instrument," says Ramsey, "should make it especially suitable for monitoring the presence of hazardous atmospheric contaminants such as ethylene oxide, formaldehyde, and many chemical warfare agents."

## Help for LMFBR Designers

Many components of liquid-metal fast breeder reactors (LMFBRs) will be subjected to higher temperatures and significantly greater thermal shocks than similar components in the current generation of light-water reactors. These components—principally those making up the reactor, intermediate heat exchanger, steam generator, and the associated piping—will eventually accumulate greater damage because of the more severe temperatures and thermal shocks over a long time. The design process must account for this damage to ensure long-term reliable component service.


Damage mechanisms that can lead to long-term component cracking, fracture, and other types of failure primarily arise out of creep and fatigue and their interactions. Creep is generally considered to be a permanent change in shape after prolonged exposure to a loading at high temperature, although under some conditions of combined creep and fatigue, creep can occur within a material with no external evidence of permanent deformation. Fatigue is the tendency of a material to break under cyclic or repeated stress and strain.

The American Society of Mechanical Engineers (ASME) has developed rules governing the design of high-temperature components, directed primarily at the LMFBR, to ensure that the reactors will withstand the necessary stresses and elevated temperatures required for a long reactor lifetime. These rules are designed to guard against time-dependent failure primarily resulting from creep and fatigue mechanisms.

ORNL's High-Temperature Structural Design Program is now assessing ASME Code rules and failure criteria to determine how accurate they are in predicting the accumulation of damage and failure in components where high-temperature, time-dependent damage mechanisms are operative. Under the leadership of Roy Huddleston of the Engineering Technology Division, engineers are conducting controlled laboratory failure tests as a basis for assessments of existing ASME code criteria and for development of improved criteria where warranted. These researchers have suggested new criteria that more nearly accurately predict when components will fail after being subjected to prolonged elevated temperature and stress histories, including thermal shock.

The current ASME rules do, however, include safety margins which have been adequate to ensure conservative life predictions in all ORNL tests to date.

Two key criteria are necessary for predicting component failure: a "damage accumulation criterion" to add up damage under variable loading histories and a "strength criterion" to account for three-dimensional stress-state effects. Using various stress and temperature tests on stainless steel components, under variable loading histories, preliminary findings of ORNL researchers for 304 stainless steel indicate that the ASME linear-time-fraction criterion for predicting creep rupture is valid for predicting failure. However, after comparing the results of biaxial (two-dimensional) creep rupture tests with those from uniaxial (one-dimensional) tests, Huddleston and his associates favor a creep-rupture strength criterion incorporating three key stress parameters (maximum principal stress, octahedral shear stress or von Mises equivalent stress, and the hydrostatic stress component) rather than the current ASME Code rules, which use a one-parameter criterion—namely, the von Mises equivalent stress or the maximum shear stress. The new criterion significantly improves life predictions, thus potentially reducing the need for dependency on excessively large design (safety) margins in life calculations and providing greater confidence for designs based upon existing safety margins.

The ORNL researchers are also actively working to develop more nearly accurate criteria for predicting the time-dependent accumulation of fatigue damage as observed in controlled tests. The researchers are now developing a new fatigue strength criterion which reduces the uncertainty in predicted component life by a factor of about two. Tests are now under way to obtain long-term data which are necessary to determine the theory that best explains the relationship between time-dependent accumulation of fatigue damage and component failure. These developments will likewise provide greater confidence in existing design margins. 



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# lab anecdote

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## **Remembrances of a Reactor Past**

At Herman Postma's State of the Laboratory address on February 1, 1983, ORNL researchers celebrated the Graphite Reactor's fortieth anniversary. This year also marks the fortieth anniversary of ORNL (originally called Clinton Laboratories) and of 29 ORNL staff members.

In our anniversary toast to the Graphite Reactor, ORNL, and the 29 members of the '43 Club, the *Review* recounts several colorful anecdotes that have been told about the X-10 Pile, known to tourists as the world's first operating nuclear reactor.

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The 1-MW, air-cooled reactor was built in only nine months and was ready to go critical in late October 1943. To celebrate the event, Martin Whitaker, director of Clinton Laboratories, summoned members of the Chicago physics group to be on hand for reactor start-up. Among the scientists who came to Oak Ridge were Arthur Compton, head of the University of Chicago Metallurgical Laboratory, and Enrico Fermi, under whose direction the first self-sustaining nuclear chain reaction was achieved on December 2, 1942, at the west stands of the University of Chicago athletic field. The visiting scientists stayed at the guest house, now known as the Alexander Motor Inn.

Starting in the afternoon of November 3, 1943, two teams of scientists began the monotonous task of loading the last of the uranium slugs into the central portion of the core. To keep from getting bored and to make time seem to pass faster during the long night, the teams decided to compete with each other in loading in the slugs. As a result, they neared the criticality point way ahead of schedule. Before dawn on November 4, the Chicago "brass" had to be awakened. At 5 a.m., Compton and Fermi left the guest house on a gray fall morning to witness the initial operation of the world's first pile to produce sizeable quantities of heat. Needless to say, the Oak Ridge teams who loaded the last of the 30 tons of uranium found the event amusing as well as historically significant.

...

The Graphite Reactor is famous for several reasons. Its first samples of plutonium, which were sent to Los Alamos in 1944, caused revolutionary changes in weapons development. It produced radioactive isotopes important to medicine, science, and industry. It provided an abundant supply of neutrons for basic research in physics and biology. Also, it was the home for the discovery of a "missing" element in the periodic table.

In 1944 Larry Glendenin and Jack Marinsky separated element 61 from fission products at the Graphite Reactor. In 1946, Glendenin and Marinsky left Oak Ridge for graduate work under Charles Coryell, a former Oak Ridge who had accepted a professorship at the Massachusetts Institute of Technology. There they searched the literature and decided to enter a claim as the rightful discoverers of element 61. Their next step was to consider an appropriate name for it.

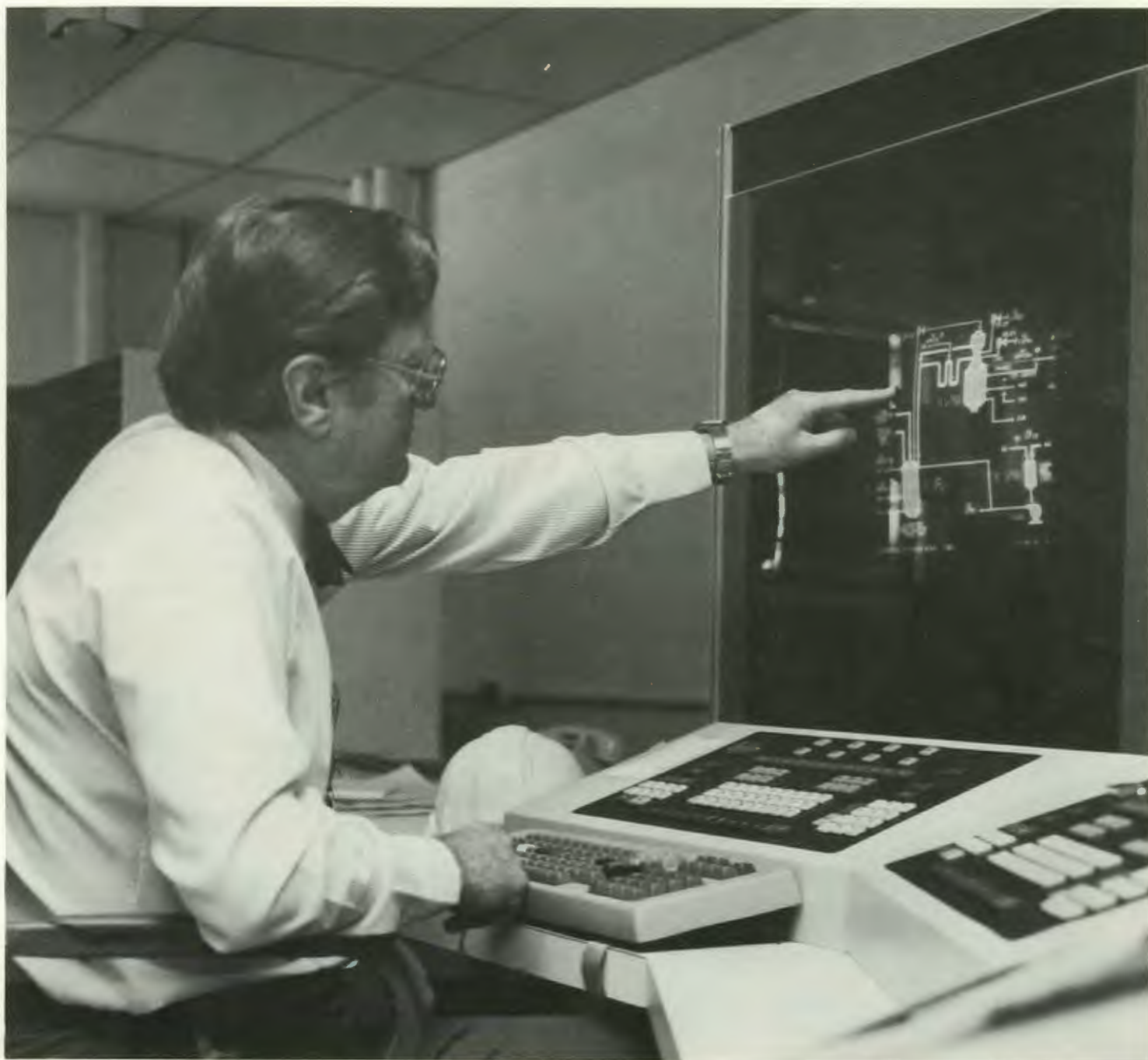
How the final name was arrived at is explained in Glendenin's account in the Fall 1976 issue of the *Review*: "Some of the possibilities to be discarded were phoenicium (phoenix rising from the ashes of nuclear fission) and clintonium (after Clinton Laboratories). The final choice of 'promethium' was suggested by Charles Coryell's wife Gracemary, who died in 1965. The name refers to Prometheus, the Titan in Greek mythology, who stole fire from heaven for the use of mankind. It not only symbolizes the dramatic way in which the element is produced as a result of the harnessing of the energy of nuclear fission but also warns of the danger of punishment by the vulture of war."

...

It is commonly held that the first generation of electricity from nuclear fission occurred in 1951 at the Experimental Breeder Reactor (EBR-1) in Arco, Idaho. Not so, according to Miles Leverett, first director of the Technical Division at Clinton Laboratories. In the Fall 1976 issue of the *Review*, he wrote that in 1945 the Graphite Reactor became the world's first nuclear source of electricity.

"That pile . . . was a very stable, well-balanced reactor, so there often was little for the night crews of operators and engineers to do. To pass the time (and prove a principle), they made an aluminum thimble, inserted it in one of the side holes of the reactor, connected it up to a water supply, and put one of the aluminum-canned fuel slugs in it. The resultant steam was led to a toy steam engine which turned a small generator and lighted an electric lamp bulb. This feat is reported to have vastly annoyed top brass in the Manhattan Project and Army." **ornl**





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## Safeguarding Reprocessing Plants

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**F**or many years, the safeguards community was concerned with scenarios of armed assault on nuclear facilities, resulting in stolen weapons material and makeshift bombs. In response, the

Department of Energy developed systems of vehicle barricades, double isolation fences, Israeli taut wire, and other sensors that could be employed at nuclear facilities to protect against the external

adversary. That technology seems reasonably mature today.

According to Howard Kerr, an Engineering Technology Division safeguards expert assigned to the Fuel Recycle Division, the domestic



John Wachter points out the process schematics and data available on the console of the safeguards computer of the Integrated Equipment Test facility. The computer is an important tool for accessing process data, such as measurements of uranium in solution in the accountability tanks. Computer programs provide messages that the safeguards operator uses to assess whether nuclear materials have been lost from the system because of diversion, leaking equipment, or faulty instruments.

Howard Kerr shows how small volumes of process solutions will be removed from the Integrated Equipment Test facility vessels during tests to determine the loss detection sensitivity of the advanced safeguards systems. Some removals would be announced to the safeguards operators while other removals that simulate clandestine diversions would be unannounced.

safeguards community has since focused its attention on what may be a more likely threat—the internal adversary. “Now, the concern is that the most likely problem may be the disgruntled employee who works at a reactor or reprocessing plant,” says Kerr. “We have to protect against unhappy employees who might want to divert material or sabotage facilities for monetary gain, sabotage, or revenge.

“Without an effective safeguards system,” Kerr continues, “these people may have the knowledge and access to disable a multibillion-dollar plant. Such an action could cause releases of radiation and serious financial losses. Safeguards are needed that will be effective against an inside adversary.”

Kerr and his colleague John Wachter are involved in the development of a safeguards system for remotely operated, computerized reprocessing facilities contemplated for the future. These facilities could use technology being developed in the Integrated Equipment Test Facility (IET) in the Fuel Recycle Division. IET is a nonradioactive reprocessing test system in which



many concepts for advanced systems and techniques for reprocessing plants are under development. In thinking about how to integrate new advances in hardware and software into a safeguards system for a future facility, says Kerr, “We have the rare opportunity of working with a plant in the early design stages where facility features are just lines on paper instead of actual steel and concrete. It doesn’t cost very much to erase the lines and draw new ones.”

### Barnwell Experiments

The ORNL researchers plan to conduct safeguards experiments in the IET. Some of these experiments may be similar to those done in the “miniruns” that ORNL conducted at the Allied-General Nuclear Services plant in Barnwell, South Carolina (a reprocessing plant not yet in operation). During these 1981

miniruns, Wachter and his associates tested their “microscopic process monitoring” software. They had developed these computer programs to detect process anomalies which could indicate fuel diversion.

“The Barnwell plant was operating with natural uranium when we tested our safeguards computer programs to see if we could detect an anomaly in the process when fuel was removed,” said Wachter. “Our computer tapped into all the instruments, which provided information on uranium solutions in the system’s tanks.

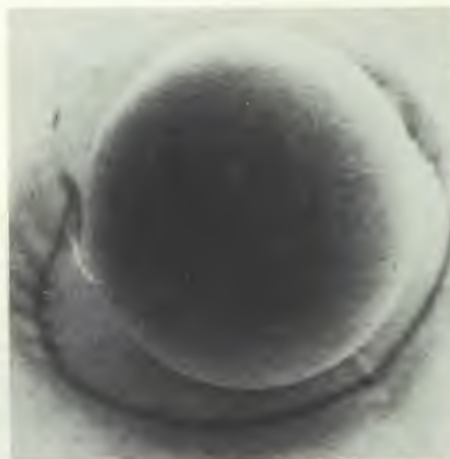
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*This is the second in a series of two articles on nuclear fuel reprocessing. This article on safeguards and the previous article on the Integrated Equipment Test facility, which appeared in the Winter 1983 issue of the Review, were both written by Carolyn Krause, Review editor, with the assistance of technical experts in the Fuel Recycle Division.*



*Scanning electron micrographs of resin beads before and after analysis in the ORNL-developed tandem magnet-type mass spectrometer.*

*David Donohue of ORNL analyzes resin bead samples for uranium and plutonium with the tandem magnet-type mass spectrometer at International Atomic Energy Agency headquarters in Vienna, Austria. This instrument, developed and built at ORNL and shipped to Vienna in 1975, is still being used for safeguards purposes.*



## ORNL Helps IAEA

Although Oak Ridge researchers are more involved with domestic safeguards for reprocessing plants, three ORNL chemists are responsible for a development now being used by the International Atomic Energy Agency (IAEA) in Japan. These researchers are Joel Carter, Ray Walker, and Dave Smith of the Analytical Chemistry Division.

IAEA officials make periodic on-site inspections as part of the effort to verify that no diversion has taken place at a reactor or reprocessing plant in any of the 110 member nations who signed the 1968 Nonproliferation Treaty. From each reprocessing facility, an inspector takes a sample of spent fuel in dissolver solution; samples are then analyzed in Vienna for the isotopic compositions and concentrations of uranium and plutonium. All fissionable isotopes must be accounted for, and the quantities of uranium and plutonium should be present in a specific ratio if no tampering has occurred.

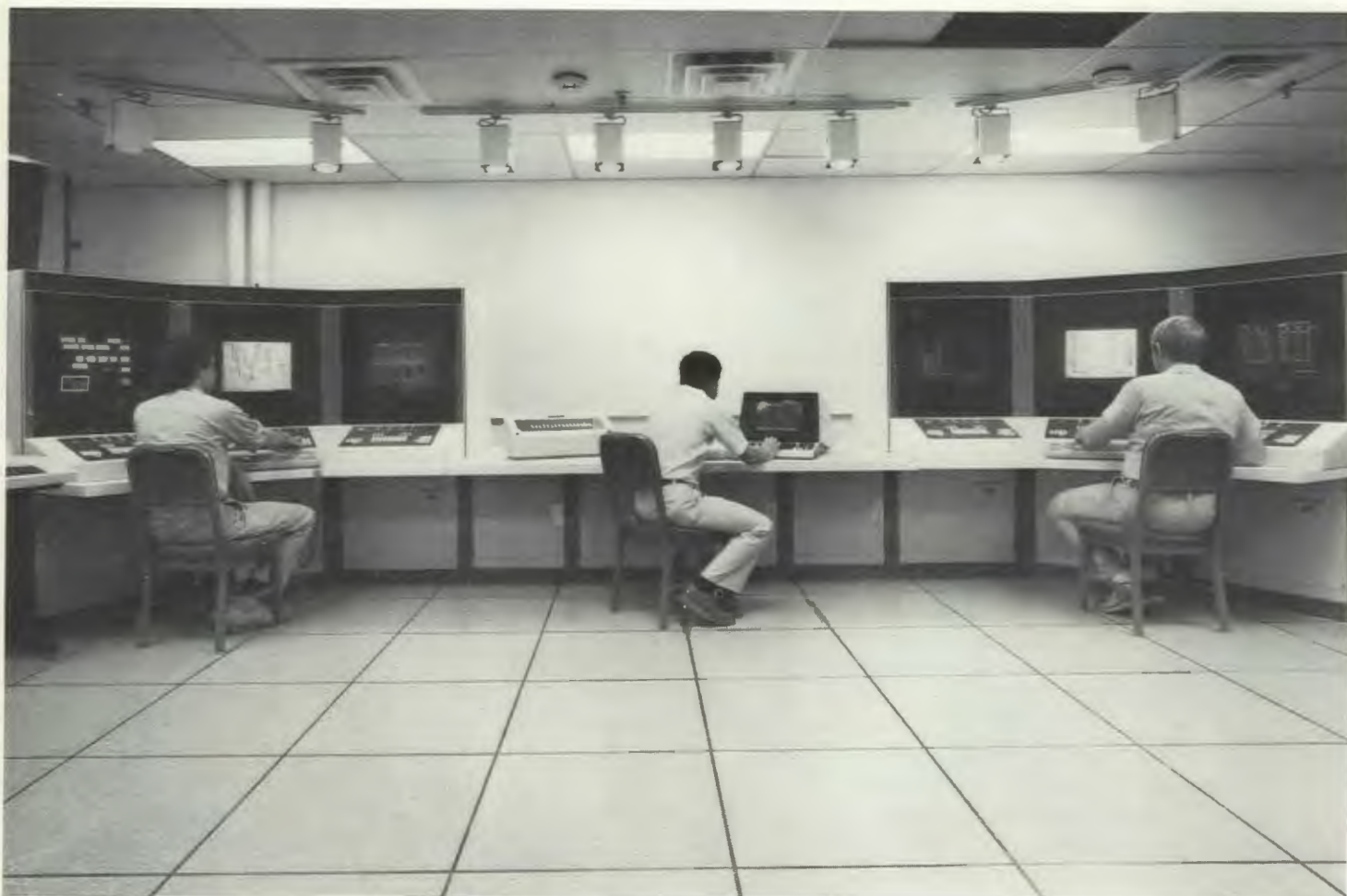
The problem is that the IAEA must obtain samples of 10–30  $\mu\text{g}$  apiece because this quantity is required for

accurate analysis with conventional mass spectrometers. Unfortunately, Japan and other countries have legal restrictions against shipping plutonium in the amounts that IAEA needs for conventional analysis at Vienna headquarters.

Carter, Walker, and Smith have come up with a winning combination to lick this problem: an ion-exchange "resin bead" technique and a tandem magnet-type mass spectrometer equipped with pulse counting. The resin beads, about the size of sugar grains, pick up traces of uranium and plutonium from the dissolver solution. Because these beads pose no radiation hazard and can be easily transported on microscope slides with no expensive shielding, they can be legally mailed to Vienna. There the beads are analyzed by an ORNL-designed mass spectrometer.

IAEA inspectors use the ORNL technique for reprocessing plants in West Germany and Japan and are expected to employ the technique internationally later this decade.





*John Allred (left), Ken Manoni, and Arnold Beets work at the operator consoles of the process control computers of the Integrated Equipment Test facility. The IET process control system provides access to all process data in a centralized computer and permits operation of the entire plant from this central control room. Such a design approach has safeguards advantages in that it localizes all human contact with the process and permits full monitoring of all process variables.*

"One day a technician took a container and filled it with some material from one point in the system. He repeated this action several times as he faked a diversion of nuclear fuel from a reprocessing plant. We were generally able to detect this loss of material, in some cases as little as 1 L, while the diversion was taking place."

The significance of this process monitoring capability, says Wachter, "can be appreciated if you recognize that several 210-L (55-gal) drums of solution must be removed from most process streams in order to obtain a few kilograms

of plutonium. We hope to continue making improvements in our monitoring techniques so that we can detect process anomalies even during dynamic plant operation."

During the miniruns at Barnwell, ORNL's colleagues from Los Alamos National Laboratory (LANL) employed a near real-time accounting system, a series of computer programs developed to estimate inventories of nuclear material on a timely basis. (LANL is the lead laboratory responsible for material accounting concepts for DOE, while Sandia National Laboratory has the lead responsibility for developing

physical protection concepts.) The LANL system allows operators to account for the material balances of the plant every hour—that is, to keep track of where and how much nuclear fuel is in the system and to compare total output with total input on a timely basis.

### **Red Flag**

These software systems are designed to raise a "red flag" to alert the reprocessing plant safeguards staff to an anomaly in the process or an unexpected loss of fuel. This information, which may signal a leaking component or an actual theft of nuclear material, is of interest not only to the safeguards staff but also to plant operators, who are concerned about personnel safety as well as profits and losses.



The new systems allow detection and identification of an unanticipated loss of special nuclear material while it is occurring or a short time after it happens. These capabilities are major additions to conventional accounting systems

used in existing plants. Many of the older plants were built when little emphasis was given to timely safeguards. These plants were not designed to accommodate improvements, such as the new safeguards ideas, over the

conventional accounting system, and the few instruments installed were primarily for process control purposes. Extensive plant improvements have been made to provide effective safeguards in existing plants, but incorporation at

## ORNL Develops Techniques for Safeguards

ORNL engineers and analytical chemists have developed several devices and techniques that could help guard against diversion of nuclear materials from reprocessing plants.

One example is a remotely operated, computer-controlled liquid sampler developed by ORNL and subcontractors. This automated sampler moves along a track inside the process canyon and removes samples at specified sample stations to be analyzed at a central analytical laboratory. In previous reprocessing plant designs, the sample lines run through the containment walls into a gallery where workers perform various operations, including extracting samples at a number of stations for analysis. The remote sampler eliminates the need for pipes in the work area, thus protecting employees from needless exposure to radioactive material and removing potential access points from which nuclear material could be diverted.

Ed Blakeman of the Engineering Technology Division and Bud Ricker of the Instrumentation and Controls Division have developed and tested nondestructive assay machines that can accurately measure the nuclear material content of fuel assemblies discharged from a reactor and delivered to a reprocessing plant. A similar machine could be used to determine the amount of residual nuclear fuels in the metallic scrap discharged from the reprocessing plant.

Some of the advanced safeguards measures that could be used in future reprocessing plants would depend on the availability of "in-line" or "at-line" measurement capabilities. Some of these advanced techniques for keeping track of nuclear materials have been developed at ORNL by Analytical Chemistry Division researchers.

Richard Brooksbank and Pamela Howell use energy-dispersive x-ray fluorescence to measure uranium and plutonium concentrations simultaneously in both the aqueous and organic streams obtained following removal of highly radioactive fission products. In this technique, X rays excite uranium, causing it to emit photons. The

intensity of the fluorescence can be correlated with uranium and plutonium concentrations.

Normally, highly radioactive fission products in dissolver solutions interfere with measurements of the uranium and plutonium content. John Keller, however, has successfully taken spectra of uranium L- $\alpha$  lines with an x-ray fluorescence spectrometer designed by Cullie Sparks of the Metal and Ceramics Division for operation in an environment with high gamma activity. This spectrometer will simultaneously detect both uranium and plutonium. In this technique, characteristic X rays are emitted when uranium and plutonium are excited by incoming X rays. The intensity of the emitted X rays can be corrected with concentrations of nuclear materials.

Debbie Bostick, Dave McCue, and Ed Strain are using optical absorption spectrometry to measure uranium and plutonium concentrations in solutions from which most fission products have been removed. These researchers pass light at several different wavelengths through quartz fibers into several in-line optical cells. There some of the light is absorbed by uranium and/or plutonium, and the rest is directed back through the fibers and measured by a photomultiplier tube. The attenuated light provides a real-time measurement of the amount of these nuclear materials directly in the process stream.

Another technique that can be potentially used for safeguards measurements is resonance ionization mass spectrometry (RIMS), developed by David Donohue and Jack Young. (See page 14 of the "State of the Laboratory" address.) RIMS may be used for a more precise measurement of plutonium-241, which has been difficult to analyze for because of interferences from americium-241, another isotope of the same mass.

"These and other analytic concepts," says safeguards expert Howard Kerr, "can be combined with mechanical concepts such as small bypass loops and fiber optic linkage to create useful measurement systems for future application."



the plant design level is undoubtedly more cost effective.

"It is very difficult to keep track of every gram of nuclear material," says Kerr. "In the early days of nuclear energy development, the rule was that the accounting

system had to be able to detect apparent losses greater than 1% of throughput. That sounds reasonable for a small plant with a few hot cells or glove boxes. Losses of only a few fractions of a kilogram over a period of a year would be detected.

"But for a large breeder fuels reprocessing plant, a 1% loss could amount to one kilogram per day or more. That accounting rule needs to be revised because it doesn't provide assurances that are meaningful for these future plants. An atomic bomb could be made with a few kilograms of plutonium.

"The international safeguards community is talking about requiring safeguards systems in reprocessing plants to be able to detect losses as small as 2 to 8 kg. This goal may be extremely difficult to achieve in large, future plants, even with these advanced concepts. Our goal is to identify a detection system that is achievable, reasonable, and meaningful and that will provide assurances that materials are not being diverted. We want to have a cost-effective safeguards system that is highly compatible with the objectives of plant operators."

#### **Inherent Advantages**

According to Kerr, a remotely operated reprocessing plant has inherent safeguards advantages. Under ORNL's Remotex concept, men and materials are separated by machines as well as thick walls for radiation shielding. By punching a few buttons or pressing keys on a computer terminal, the operator can manipulate from a long distance the equipment that runs or alters the process.

"The safeguards system must be capable of monitoring the actions of the operator who is remotely manipulating equipment and

*Paul Pair of ORNL's Analytical Chemistry Division uses the computer-controlled remote pipetter in a hot cell for dispensing a measured amount of a highly radioactive solution typical of a fuel reprocessing facility. The Analytical Chemistry Division is developing techniques to measure the precise concentrations of uranium and plutonium in reprocessing solutions in support of the safeguards effort.*





*John Wachter examines several of the numerous process sensors that provide data that are essential for both process operation and effective safeguards in a reprocessing plant. Advanced safeguards concepts have been developed that use process data to determine the location and amount of nuclear material in the facility.*





materials in a cell or canyon," says Kerr. "Monitoring equipment will be used to verify that the operator's actions are consistent with proper plant operation. Some may object that such a safeguards system is too intrusive, too reminiscent of 'Big Brother.' But, just as bank tellers have to be audited for cash shortages, reprocessing plant operators must accept that their performance will be closely monitored for economic as well as safeguards reasons."

Kerr's expertise in safeguards is valued not only in Oak Ridge but also in Washington, D.C. and Europe. Recently, he testified for DOE on the question of whether Clinch River Breeder Reactor fuel can be safeguarded in the reprocessing step of the nuclear fuel cycle.

"My opinion is that CRBR fuels can be effectively safeguarded during reprocessing, with minimal economic impact. The facility at which CRBR fuels would be reprocessed has not yet been identified, but the needed technology is known. I noted that the CRBR fuel cycle would include less than one metric ton of plutonium a year. We are already handling much more plutonium annually in DOE facilities, which have adequate safeguards. So the problems are surely manageable."

### International Safeguards

Kerr also is concerned with international safeguards, the province of the 25-year old International Atomic Energy Agency (IAEA), a United Nations agency in Vienna, Austria. In 1980-81, he spent seven weeks in Vienna studying the technical problems of international safeguards as a member of the International Working Group for Reprocessing Plant Safeguards, which was established by IAEA.

"One prevalent fear," explains Kerr, "is that nuclear power

reactors and reprocessing plants are a ready source of nuclear fuel for weapons. But, they really are not the easiest, least costly way for a nonweapons state to make atomic bombs.

"The nuclear-weapons states—the United States, Great Britain, France, Russia, and China—make nuclear weapons at dedicated plutonium production facilities. Another method is to irradiate uranium-238 in a small research reactor to make plutonium. That's what India did and what Israel apparently thought Iraq was about to do before the Israeli attack on the Osirak reactor in June 1981."

Kerr adds that a third method for obtaining bombs is to attack a weapons production facility, military base, or airplanes loaded with fabricated nuclear weapons. "The pathway to nuclear weapons is not limited to the fuel cycle, as commonly believed," he observes.


"A large reprocessing plant or nuclear power reactor may cost at least \$2 billion and produce hundreds of millions of dollars worth of fuel or electricity annually. It would be possible for a country to divert fuel from such a facility for the purpose of making nuclear weapons, but this act could easily be detected by an effective safeguards system and would have enormous political and economic implications. It would seem to me to be relatively more economical and manageable for an outlaw nation to obtain nuclear weapons by building small dedicated facilities."

Kerr's reasoning agrees with that of the International Nuclear Fuel Cycle Evaluation (INFCE), an international study called for by President Carter in which many from ORNL participated. One INFCE conclusion was that the possibility for theft of bomb-making materials cannot be eliminated by foregoing reprocessing plants and breeder

reactors. This conclusion was welcomed by the Europeans and Japanese, who want both types of facilities to avoid their heavy reliance on imported oil and imported uranium for energy sources.

As for the problem of terrorists seizing nuclear fuel, Bernard Goldschmidt, author of *The Atomic Complex*, notes that "a would-be terrorist has means at his disposal, far less dangerous to himself than the theft of plutonium, with which to terrorize a population." Although plutonium is radioactive and toxic, Kerr thinks that other toxic substances such as radium and many biological poisons could more easily be used by terrorists.

Kerr notes that the safeguards community has come up with many gadgets to detect diversion, including radiation detectors for surveillance inside and outside nuclear facilities and the RECOVER (for REmote Continuous VERification) system of electronic hardware for transmitting data to Vienna in order to reveal whether anyone has tampered with television cameras installed by IAEA to monitor reactor fuel-loading and storage areas.

A major fraction of the technological needs of the safeguards community, he believes, has been adequately met by current developments in hardware and software. "The gadgeteering phase is winding down," says Kerr. "The next phase of safeguards is assessing how best to hook up all these tools into a cost-effective, integrated system. That's what we are trying to do in the IET." 



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## awards and appointments

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**Jagdish Narayan** and **G. Malcolm Stocks** have been named fellows of the American Physical Society.

**Steve Kaye** has been appointed a member of the Subcommittee on High-Level Radioactive Waste of the Science Advisory Board of the U.S. Environmental Protection Agency.

**David Greene** has been named chairman of the Committee on Energy Conservation and Transportation Demand of the Transportation Research Board of the National Academy of Sciences/National Research Council (NAS/NRC). He is also chairman of the NAS/NRC Subcommittee on Forecasting Transportation Energy Demand.

**Dorothy M. Skinner** has been named chairperson-elect of the Biological Sciences Section of the American Association for the Advancement of Science. This is the largest section in the 140,000 member society.

**Charles S. Yust** and **W. J. Lackey** have been elected chairman and vice-chairman, respectively, of the Nuclear Division of the American Ceramic Society.

**E. J. Frederick** and **H. W. Godbee** received certificates of appreciation from the U.S. Department of Energy for organizing the Alpha-Contaminated Waste Management Workshop, which was held in August 1982.

**Wally Koehler** has been named corecipient of the third annual Frank H. Spedding Award for his rare-earth research.

**Liane B. Russell** has been chosen president-elect of the Environmental Mutagen Society.

**Tom Oakes** has been appointed to a five-year term on the Union Carbide Corporation Solid Waste Issues Committee.

**Myron F. Fair** recently received the annual "distinguished service award" of the East Tennessee Chapter of the Health Physics Society.


**John F. Alexander, Brian A. Kelly, Michael T. Ryan, and David R. Simpson** have been certified by the American Board of Health Physics.

Two ORNL staff members received awards in the 1982-83 International Technical Publications Competition sponsored by the Society for Technical Communication. **Jon Jefferson**, associate editor of the ORNL *Review*, received an award of merit in the news article category for "Facility Will Simulate Pressurized Thermal Shock," August 1982 issue of *Lab News*. **Ginger Ross** (along with Jack Kratchman and Judy Joyner) received an award of achievement in the bulletins and brochures category for *United States Gaseous Diffusion Program for Uranium Enrichment*.



At the 1983 publications competition sponsored by the East Tennessee Chapter of the Society for Technical Communication, the following ORNL staff members received awards: **Deborah Barnes**, award of merit in the category of annual reports for *ORNL Trends and Balances, 1982-1987*; **Ginger Ross**, award of achievement in annual reports for *1981 Uranium Enrichment Annual Report*; **William D. Burch**, award of distinction in bulletins and brochures for *Fuel Recycle Division Long-Range Plan FY 1982-1987*; **John Getsi**, **Judy Crutcher**, and **Linda Jeffers**, award of excellence in bulletins and brochures for *Information Center Complex*; **Vivian Jacobs**, award of excellence in bulletins and brochures for *Fourth Annual DOE LLWMP Participants' Information Meeting*; **Ginger Ross**, award of excellence in bulletins and brochures for *United States Gaseous Diffusion Program for Uranium Enrichment*; **Martin S. Lubell**, **Ethel Cagle**, and **David Baumgardner**, award of achievement in bulletins and brochures for *1982 Applied Superconductivity Conference: Preliminary Program*; **George Moore** and **Joyce Francis**, award of achievement in bulletins and brochures for *In-Hours Continuing Education Program for Scientific and Technical Personnel*; **James B. Roberto**, award of achievement in bulletins and brochures for *Fifth International Conference on Plasma Surface Interactions in Controlled Fusion Devices*; **Robert Eldridge**, award of achievement in bulletins and brochures for *United States*

*Uranium Enrichment Program and Facilities*; **Barbara Lyon**, **Carolyn Krause**, and **Bill Clark**, award of achievement in house organs for the *ORNL Review*; **William B. Cottrell** and **Sharon McConathy**, award of excellence in journals for *Nuclear Safety*; **Irene Brogden**, **D. P. Stinton**, **W. J. Lackey**, **Pete Angelini**, and **A. J. Caputo**, award of distinction in journal articles for "Coating of Crystalline Nuclear Waste Forms to Improve Inertness," *Journal of the American Ceramic Society*; **James Joyce** and **Jane Parrott** (with D. W. Moeller of Harvard University and D. W. Underhill of the University of Pittsburgh), award of excellence in journal articles for "Review and Evaluation of Factors Affecting Noble-Gas Adsorption on Activated Carbon," *Nuclear Safety*; **Carolyn Krause**, award of merit in journal articles for "Images of the Heart: ORNL Makes Isotopes for Disease Detection," *ORNL Review*; **Barbara Ashdown**, **D. P. Stinton**, **W. J. Lackey**, and **R. D. Spence**, award of merit in journal articles for "Production of Spherical  $\text{UO}_2\text{-UC}_2$  for Nuclear Fuel Applications Using Thermochemical Principles," *Journal of American Ceramic Society*; **L. K. Felker**, **B. Z. Egan**, **A. D. Kelmers**, **F. G. Seeley**, and **Martha Stewart**, award of achievement in journal articles for "Aluminum from Fly Ash," *CHEMTECH*; **Elias Greenbaum** and **Luci Bell**, award of achievement in journal articles for "Photosynthetic Hydrogen and Oxygen Production: Kinetic Studies," *Science*; **Jon Jefferson** and **Robert Eldridge**, award of

excellence in newsletters for *Lab News*; **Jon Jefferson**, five prizes in news articles in *Lab News*: "Earth-Sheltered Houses: New Look at an Old Idea" (award of distinction), "Facility Will Stimulate Pressurized Thermal Shock" (award of excellence), "Reactor-Safety Expert Rates Risks, Risk Analysis" (award of excellence), "ORNL Works with Sagan's Planetary-Studies Lab" and "Titan: Deep-Frozen Ingredients for Life?" (award of merit), "ORNL Proposing Neutron-Antineutron Experiment to DOE" and "Experiments Elsewhere Seek Elusive Proton Decay" (award of achievement), **Carolyn Krause**, award of achievement in news articles for "Pocket Monitors for Airborne Pollutants," *ORNL Review*; **S. I. Auerbach** and **Ralph Sharpe**, award of distinction in periodic progress reports for *Environmental Sciences Division Annual Progress Report for Period Ending September 30, 1981*; **William Fulkerson** and **Tykey Truett**, award of excellence in periodic progress reports for *Energy Division Annual Progress Report for Period Ending September 30, 1981*; **Donald E. Ferguson**, award of merit in periodic progress reports for *Chemical Technology Division Progress Report for the Period Ending April 1, 1979*; **John Sheffield**, **Bonnie Johnson**, **S. R. Schwartz**, and **Ethel Cagle**, award of merit in topical reports for *Fusion Research at ORNL*; and **R. L. Wendt** and **L. D. Gilliam**, award of achievement in topical reports for *Earth-Sheltered Housing: An Evaluation of Energy-Conservation Potential*. 

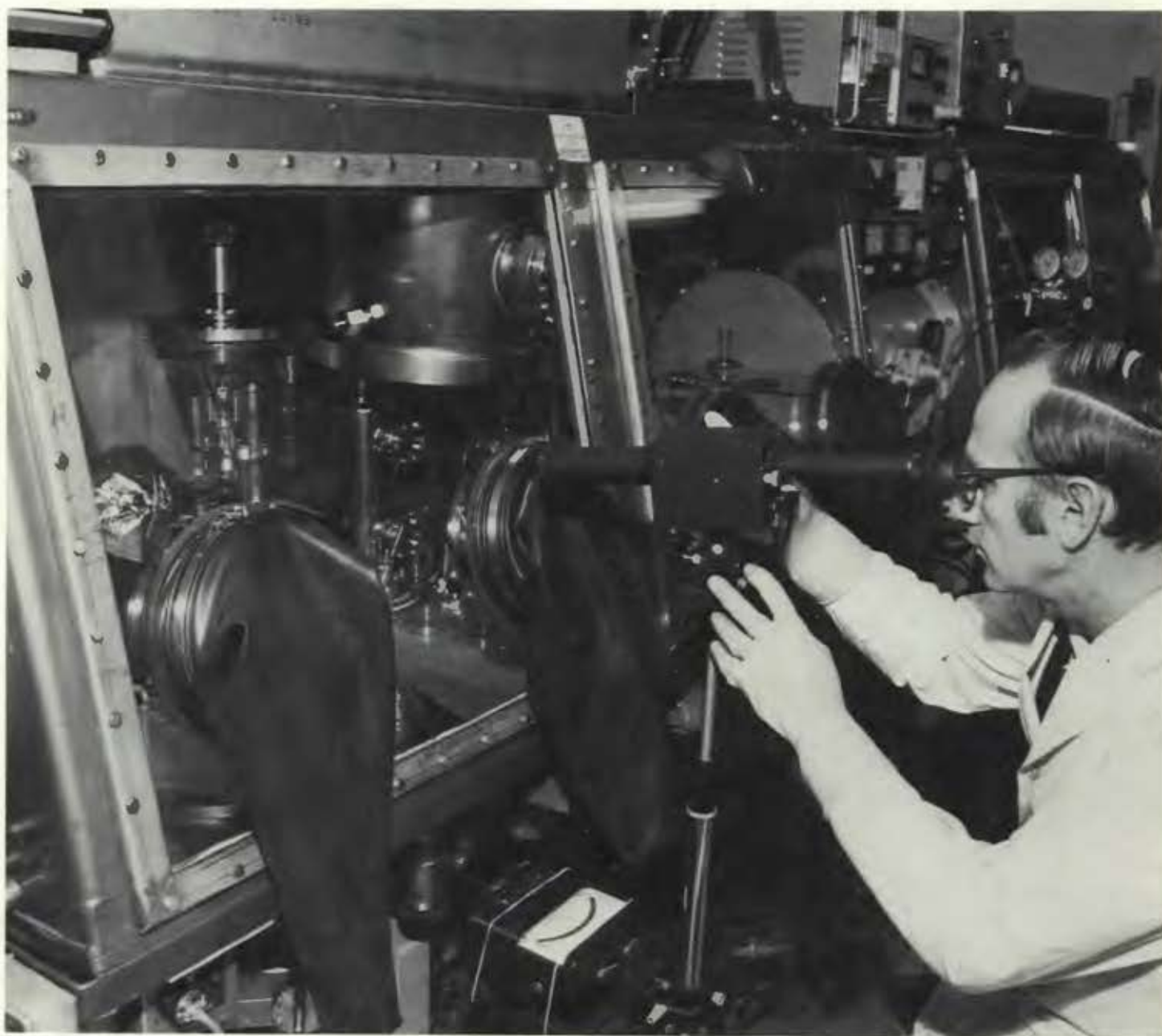


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Dick Hahn peers through a pyrometer into a glove box where he has prepared a heated metallic sample of a transuranium element. Transuranium research is discussed in detail in Dick Hahn's "Life at the End of the Periodic Table" on page 24.